Global Positioning System (GPS) Standard Positioning Service (SPS) Performance Analysis Report

Submitted To

Federal Aviation Administration

GPS Product Team

1284 Maryland Avenue SW

Washington, DC 20024

Report #89

April 30, 2015

Reporting Period: 1 January – 31 March 2015

Submitted by

William J. Hughes Technical Center

WAAS T&E Team

Atlantic City International Airport, NJ 08405

Executive Summary

The GPS Product Team has tasked the Navigation Systems Verification and Monitoring Branch at the William J. Hughes Technical Center to document the Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS Performance Analysis (PAN) Reports. The report contains the analysis performed on data collected at twenty-eight Wide Area Augmentation System (WAAS) Reference Stations. This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification (September 2008).

This report, Report #89, includes data collected from 1 January through 31 March 2015. The next quarterly report will be issued July 31, 2015.

Analysis of this data includes the following standards and categories: PDOP Availability, NANU Summary and Evaluation, Service Availability, Position and Range Accuracy and Solar Storm Effects on GPS SPS performance.

PDOP availability is based on Position Dilution of Precision (PDOP). Utilizing the weekly almanac posted on the US Coast Guard navigation web site, the coverage for every 5^o grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the global availability based on PDOP less than six for CONUS was 100%.

NANU summary and evaluation was achieved by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 January and 31 March 2015. Using this data, we compute a set of statistics that give a relative idea of constellation health for both the current and combined history of past quarters. A total of seven outages were reported in the NANU’s this quarter. Six outages were scheduled ahead of time while one outage was an unscheduled NANU sent out after the start of the event.

The quarterly service availability standard was verified using 24-hour position accuracy values computed from data collected at one-second intervals. All of the sites achieved a 100% availability, which exceeds the SPS “average location” value of 99% and the “worst-case location” value of 90%.

Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error standard was verified for each satellite from 24-hour accuracy values computed using data collected at the following six sites: Boston, Honolulu, Los Angeles, Miami, San Juan and Juneau. This data was also collected in one-second samples. All sites achieved 100% reliability, meeting the SPS specification. The maximum range error recorded was 26.411 meters on Satellite PRN 14. The SPS specification states that the range error should never exceed 30 meters for less than 99.79% of the day for a worst-case point and 99.94% globally. The maximum RMS range error value of 2.817 was recorded on satellite PRN 10. The SPS specification states that RMS URE cannot exceed 6 meters in any 24-hour interval.

Geomagnetic storms had little to no effect on GPS performance this quarter. All sites met all GPS Standard Positioning Service (SPS) specifications on those days with the most significant solar activity.

The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products. During the evaluation period, the maximum 95% horizontal and vertical SPS errors were xxx meters at xxx Maspalomas, Spain and xxx meters at xxx.

From the analysis performed on data collected between 1 January and 31 March 2015, the GPS performance met all SPS requirements that were evaluated.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS and WAAS for IFR operations and is developing Local Area Augmentation (LAAS), which is an additional GPS augmentation system. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Analysis report. This report contains data collected at the following twenty-eight WAAS reference station locations:

- Bethel, AK
- Billings, MT
- Fairbanks, AK
- Cold Bay, AK
- Kotzebue, AK
- Juneau, AK
- Albuquerque, NM
- Anchorage, AK
- Boston, MA
- Washington, D.C.
- Honolulu, HI
- Houston, TX
- Kansas city, KS
- Los Angeles, CA
- Salt Lake City, UT
- Miami, FL
- Minneapolis, MI
- Oakland, CA
- Cleveland, OH
- Seattle, WA
- San Juan, PR
- Atlanta, GA
- Barrow, AK
- Merida, Mexico
- Gander, Canada
- Tapachula, Mexico
- San Jose Del Cabo, Mexico
- Iqaluit, Canada

The analysis of the data is divided into the four performance categories stated in the Standard Positioning Service Performance Specification (September 2008). These categories are:

- PDOP Availability Standard
- Service Availability Standard
- Service Reliability Standard
- Positioning, Ranging and Timing Accuracy Standard

The results were then compared to the performance parameters stated in the SPS.

1.2 Report Overview

Section 2 of this report summarizes the results obtained from the coverage calculation program developed by the WAAS test team at the William J. Hughes Technical Center. The SPS coverage area program uses the GPS satellite almanacs to compute each satellite position as a function of time for a selected day of the week. This program establishes a 5-degree grid between 180 degrees east and 180 degrees west, and from 80 degrees north and 80 degrees south. The program then computes the PDOP at each grid point (1485 total grid points) every minute for the entire day and stores the results. After the PDOP's have been saved the 99.99% index of 1-minute PDOP at each grid point is determined and plotted as contour lines (Figure 2-1). The program also saves the number of satellites used in PDOP calculation at each grid point for analysis.

Section 3 summarizes the GPS constellation performance by providing the "Notice: Advisory to Navstar Users" (NANU) messages to calculate the total time of forecasted and actual satellite outages. This section also evaluates the Service Availability Standard using 24-hour 95% horizontal and vertical position accuracy values.

Section 4 summarizes service reliability performance. It will be reported at the end of the first year of this analysis because the SPS standard is based on a measurement interval of one year. Data for the quarter is provided for completeness.

Section 5 provides the position accuracies based on data collected on a daily basis at one-second intervals. This section also provides the statistics on the range error, range error rate and range acceleration error for each satellite. The overall average, maximum, minimum and standard deviations of the range rates and accelerations are tabulated for each satellite.

In Section 6, the data collected during solar storms is analyzed to determine the effects, if any, of GPS SPS performance.

Section 7 provides an analysis of GPS-SPS accuracy performance from a selection of high rate IGS stations around the world.

Section 8 provides a summary of GPS Test NOTAMs.

Section 9 provides four appendices to summarize the data found in this report and provide further information.

Appendix A provides a summary of all the results as compared to the SPS specification.

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

Appendix D provides a glossary of terms used in this PAN report. This glossary was obtained directly from the GPS SPS specification document (September 2008).

1.3 Summary of Performance Requirements and Metrics

Table 1-1 over the next four pages lists the performance parameters from the SPS and identifies those parameters verified in this report.

Table 1-1 SPS SIS Performance Requirements Standards

Per-Satellite Coverage	Conditions and Constraints	Evaluated in This Report
Terrestrial Service Volume: 100% Coverage Space Service Volume: No Coverage Performance Specified	• For any health or marginal SPS SIS	✓
Constellation Coverage	**Conditions and Constraints**	
Terrestrial Service Volume: 100% Coverage Space Service Volume: No Coverage Performance Specified	• For any healthy or marginal SPS SIS	✓
User Range Error Accuracy	**Conditions and Constraints**	
Single Frequency C/A-Code • ≤ 7.8m 9%% Global Average URE during normal operations over All AODs • ≤ 6.0m 95% Global Average URE during operations at Zero AOD • ≤ 12.8m 95% Global Average URE during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1	✓
Single Frequency C/A-Code • ≤ 30m 99.94% Global Average URE during normal operations • ≤ 30m 99.79% Worst Case single point average during normal operations.	• For any healthy SPS SIS. • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 • Standard based on measurement interval of one year; average of daily values within service volume • Standard based on 3 service failures per year, lasting no more than 6 hours each	✓
User Range Rate Error Accuracy	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	✓

User Range Acceleration Error Accuracy	**Conditions and Constraints**	**Evaluated in This Report**
Single-Frequency C/A-Code: • ≤ 2 mm/sec^2 95% Global average URAE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	✓
Coordinated Universal Time Offset Error Accuracy		
• ≤ 40 nanoseconds 95% Global average UTCOE during normal operations at Any AOD.	• For any healthy SPS SIS	✓
Instantaneous URE Integrity	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 1x10^{-5} Probability over any hour of the SPS SIS Instantaneous URE exceeding the NTE tolerance without a timely alert during normal operations.	• For any healthy SPS SIS • SPS SIS URE NTE tolerance defined to be ±4.42 times the upper bound on the URA value corresponding to the URA index "N" currently broadcast by the satellite. • Given that the maximum SPS SIS instantaneous URE did not exceed the NTE tolerance at the start of the hour • Worst case for delayed alert is 6 hours. • Neglecting singe-frequency ionospheric delay model errors	Please see results in the WAAS PAN report. ✓
Instantaneous UTCOE Integrity	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 1x10^{-5} Probability over any hour of the SPS SIS Instantaneous UTCOE exceeding the NTE tolerance without a timely alert during normal operations.	• For any healthy SPS SIS • SPS SIS URE NTE tolerance defined	✓
Unscheduled Failure Interruption Continuity	**Conditions and Constraints**	
Unscheduled Failure Interruptions: • ≥ 0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Given that the SPS SIS is available from the slot at the start of the hour	✓

Status and Problem Reporting	Conditions and Constraints	Evaluated in This Report
Scheduled event affecting service • Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS	✓
Unscheduled outage or problem affecting service • Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	• For any SPS SIS	✓
Per-Slot Availability	**Conditions and Constraints**	
• ≥ 0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS • ≥ 0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a health SPS SIS	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.	✓
Constellation Availability	**Conditions and Constraints**	
• ≥ 0.98 Probability that at least 21 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration • ≥ 0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration	• Calculated as an average over all slots in the 24-slot constellation, normalized annually. • Applies to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.	✓
Operational Satellite Count	**Conditions and Constraints**	
• ≥ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not	• Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operation satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.	✓

PDOP Availability	Conditions and Constraints	Evaluated in This Report
• ≥ 98% global PDOP of 6 or less • ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval	✓
Service Availability	**Conditions and Constraints**	
• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	✓
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	✓
Position/Time Accuracy	**Conditions and Constraints**	
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	✓
Worst Site Position Domain Accuracy • ≤ 17m 95% Horizontal Error • ≤ 37m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	✓
Time Transfer Domain Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for a time transfer solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	✓

2 PDOP Availability Standard

PDOP Availability: The percentage of time over any 24-hour interval that the PDOP value is less than or equal to its threshold for any point within the service volume.

Dilution of Precision (DOP): The magnifying effect on GPS position error induced by mapping GPS range errors into position within the specified coordinate system through the geometry of the position solution. The DOP varies as a function of satellite positions relative to user position. The DOP may be represented in any user local coordinate desired. Examples are HDOP for local horizontal, VDOP for local vertical, PDOP for all three coordinates, and TDOP for time.

PDOP Availability Standard	Conditions and Constraints
≥ 98% global PDOP of 6 or less ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the WAAS test team was used to calculate the PDOP at every 5^{o} point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 2.988 or better 99.9% of the time for each of the 24-hour intervals.

Figure 2-1 is a contour plot of PDOP values over the entire globe. Inside each contour area, the PDOP value is greater than or equal to the contour value shown in the legend for that color line. That areas' value is also less than the next higher contour value, unless another contour line lies within the current area. A single "DOP hole" where the PDOP value is greater than 6 was evaluated for satellite visibility for one 24-hour interval from the week shaded in Table 2-1. The histogram in Figure 2-2 shows the satellite visibility at the DOP hole position for the 24 hour interval in question.

The GPS coverage performance evaluated met the specifications stated in the SPS.

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value	Global Average (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
28 Dec – 3 Jan	2.897	100	99.722
4 – 10 Jan	2.899	99.999	99.583
11 – 17 Jan	2.913	99.999	99.514
18 – 24 Jan	2.903	99.999	99.514
25 – 31 Jan	2.901	99.999	99.514
1 – 7 Feb	2.899	99.999	99.514
8 – 14 Feb	2.916	99.999	99.514
15 – 21 Feb	2.937	99.999	99.514
22 – 28 Feb	2.957	99.999	99.444
1 – 7 Mar	2.978	99.999	99.444
8 – 14 Mar	2.988	99.999	99.375
15 – 21 Mar	2.969	99.999	99.375
22 – 28 Mar	2.928	99.999	99.306

Figure 2-1 World GPS Maximum PDOP

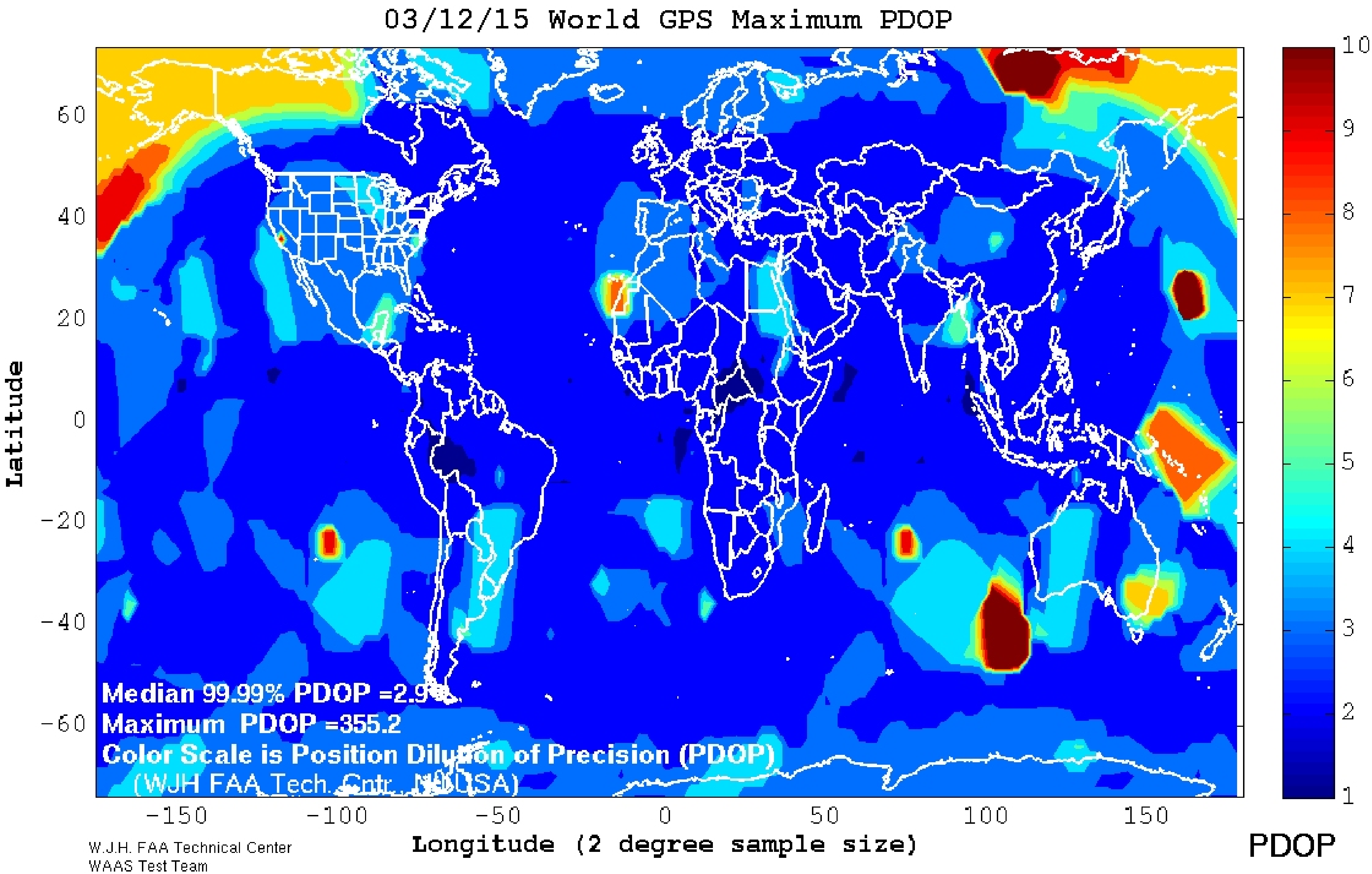
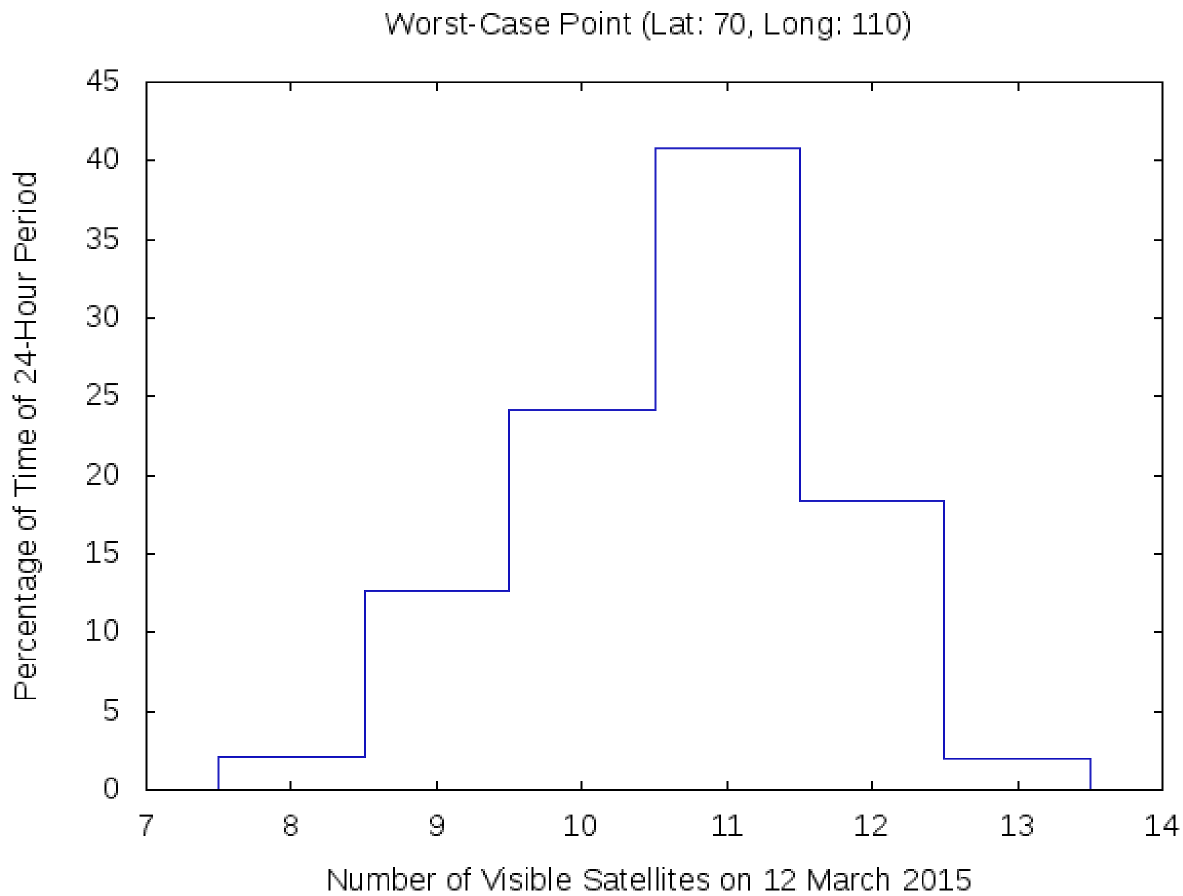


Figure 2-2 Satellite Visibility Profile for Worst-Case Point



3 NANU Summary and Evaluation

NANU: Notice Advisory to NAVSTAR Users – A periodic bulletin alerting users to changes in the satellite system performance.

Status and Problem Reporting	Conditions and Constraints
Scheduled event affecting service • Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS
Unscheduled outage or problem affecting service • Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	• For any SPS SIS

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 January through 31 March 2015, there were a total of seven reported outages. Six of those outages were maintenance activities and were reported in advance, while one was an unscheduled outage. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's (if any) are provided in Table 3-3. The minimum duration a scheduled outage was forecasted ahead of time was 74.917 hours. All notification times met or exceeded the 48-hour requirement. The maximum response time for a NANU issued for an unscheduled outage was 1.683 hours. Therefore the probability of continuity not being affected due to an unscheduled failure interruption was 100%, which met the specification requirement.

Table 3-1 NANUs Affecting Satellite Availability

NANU#	PRN	TYPE	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2015006	13	FCSTSUMM	9-Jan-15	5:44	9-Jan-15	13:30		7.77	7.77
2015009	30	FCSTSUMM	6-Feb-15	1:12	6-Feb-15	5:56		4.73	4.73
2015012	11	UNUSABLE	19-Feb-15	4:50	20-Feb-15	14:45	33.92		33.92
2015014	14	FCSTSUMM	5-Mar-15	15:12	5-Mar-15	21:28		6.27	6.27
2015016	29	FCSTSUMM	12-Mar-15	4:31	12-Mar-15	10:48		6.28	6.28
2015018	32	FCSTSUMM	20-Mar-15	9:06	20-Mar-15	15:25		6.32	6.32
2015023	32	FCSTSUMM	30-Mar-15	0:05	31-Mar-15	23:44		47.65	47.65
Totals of Unscheduled, Scheduled & Total Downtime							33.92	79.02	112.94

GENERAL NANUs

2015003 – Announced resumed transmission of L-band signal on PRN8/SVN38.

2015007 – Announced resumed transmission of L-band signal on PRN26/SVN32.

2015010 – Announced resumed transmission of L-band signal on PRN26/SVN27.

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2015001	13	FCSTDV	9-Jan	5:30	9-Jan	17:30	12	2015006
2015004	26	UNUSUFN	5-Jan	17:50				
2015008	30	FCSTDV	6-Feb	0:30	6-Feb	12:30	12	2015009
2015011	11	UNUSUFN	19-Feb	4:50				2015012
2015013	14	FCSTDV	5-Mar	15:00	6-Mar	3:00	12	2015014
2015015	29	FCSTDV	12-Mar	4:00	12-Mar	16:00	12	2015016
2015017	32	FCSTDV	20-Mar	8:30	20-Mar	20:30	12	2015018
2015020	32	FCSTMX	29-Mar	22:00	11-Apr	0:00	290	2015023
Total Forecasted Downtime							350	

Table 3-3 Cancelled NANUs

NANU#	PRN	Type	Start Date	Start Time	Comments
-	-	-	-	-	-

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published "Notice: Advisory to Navstar Users" messages (NANU's). This data has been summarized in Table 3-4. The "Total Satellite Observed MTTR" was calculated by taking the average downtime of all satellite outage occurrences. Scheduled downtime was forecasted in advance via NANU's. All other downtime reported via NANU was considered unscheduled. The "Percent Operational" was calculated based on the ratio of total actual operating hours to total available operating hours for every satellite.

Table 3-4 GPS Satellite Maintenance Statistics

Satellite Reliability/Maintainability/Availability (RMA) Parameter	1-Jan-15 31-Mar-15	1-Jan-00 31-Mar-14
Total Forecast Downtime (hrs):	350	10694.82
Total Actual Downtime (hrs):	112.94	38463
Total Actual Scheduled Downtime (hrs):	79.02	6109.39
Total Actual Unscheduled Downtime (hrs):	33.92	32353.61
Total Satellite Observed MTTR (hrs):	16.13	47.6
Scheduled Satellite Observed MTTR (hrs):	13.17	9.55
Unscheduled Satellite Observed MTTR (hrs):	33.92	192.58
# Total Satellite Outages:	7	808
# Scheduled Satellite Outages:	6	640
# Unscheduled Satellite Outages:	1	168
Percent Operational -- Scheduled Downtime:	99.88	99.85
Percent Operational -- All Downtime:	99.83	99.07

3.2 Service Availability Standard

Service Availability: The percentage of time over any 24-hour interval that the predicted 95% position error is less than the threshold at any given point within the service volume.

• **Horizontal Service Availability:** The percentage of time over any 24-hour interval that the predicted 95% horizontal error is less than its threshold for any point within the service volume.

• **Vertical Service Availability:** The percentage of time over any 24-hour interval that the predicted 95% vertical error is less than its threshold for any point within the service volume.

Service Availability Standard	Conditions and Constraints
• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.

To verify availability, the data collected from receivers at the twenty-eight WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-5. The data was collected at one-second intervals between 1 January and 31 March 2015.

Table 3-5 Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	Quarters Service Availability %
Albuquerque	7775769	0	100%
Anchorage	7775573	0	100%
Atlanta	7775760	0	100%
Barrow	7775129	0	100%
Bethel	7775481	0	100%
Billings	7773216	0	100%
Boston	7767227	0	100%
Cleveland	7775553	0	100%
Cold Bay	7774921	0	100%
Fairbanks	7775215	0	100%
Gander	7775747	0	100%
Honolulu	7430038	0	100%
Houston	7769895	0	100%
Iqaluit	7772001	0	100%
Juneau	7771290	0	100%
Kansas City	7775762	0	100%
Kotzebue	7775284	0	100%
Los Angeles	7775763	0	100%
Merida	7772108	0	100%
Miami	7775641	0	100%
Minneapolis	7759644	0	100%
Oakland	7775746	0	100%
Salt Lake City	7775548	0	100%
San Jose Del Cabo	7772555	0	100%
San Juan	7775159	0	100%
Seattle	7775746	0	100%
Tapachula	7771170	0	100%
Washington, DC	7775703	0	100%
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4 Service Reliability Standard

Service Reliability: The percentage of time over a specific time interval that the instantaneous SIS SPS URE is maintained within a specified reliability threshold at any given point within the service volume, for all healthy GPS satellites.

User Range Error Accuracy	Conditions and Constraints
Single Frequency C/A-Code • ≤ 30m 99.94% Global Average URE during normal operations • ≤ 30m 99.79% Worst Case single point average during normal operations.	• For any healthy SPS SIS. • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 • Standard based on measurement interval of one year; average of daily values within service volume • Standard based on 3 service failures per year, lasting no more than 6 hours each

Table 4-1 shows a comparison to the service reliability standard for range data collected at a set of six receivers across North America. Although the specification calls for yearly evaluations, we will be evaluating this SPS requirement at quarterly intervals. Additional range analysis results can be found in table 5-2. The maximum User Range Error recorded this quarter was 26.411 meters on satellite PRN 14.

Table 4-0-1 User Range Error Accuracy

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Percentage
1 Jan – 31 Mar 2015	**Boston**	64,681,600	0	100%
1 Jan – 31 Mar 2015	**Honolulu**	67,732,463	0	100%
1 Jan – 31 Mar 2015	**Los Angeles**	67,,096,376	0	100%
1 Jan – 31 Mar 2015	**Miami**	64,411,605	0	100%
1 Jan – 31 Mar 2015	**Merida**	67,105,248	0	100%
1 Jan – 31 Mar 2015	**Juneau**	66,957,576	0	100%
1 Jan – 31 Mar 2015	**Global**	397,984,868	0	100%

5 Accuracy Standard

Positioning Accuracy: The statistical difference, at a 95% probability, between position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

• **Horizontal Positioning Accuracy**: The statistical difference, at a 95% probability, between horizontal position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

• **Vertical Positioning Accuracy**: The statistical difference, at a 95% probability, between vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

Position/Time Accuracy	Conditions and Constraints
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.
Worst Site Position Domain Accuracy • ≤ 17m 95% Horizontal Error • ≤ 37m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.
Time Transfer Domain Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for a time transfer solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.

User Range Accuracy	Conditions and Constraints
Single Frequency C/A-Code • ≤ 7.8m 9%% Global Average URE during normal operations over All AODs • ≤ 6.0m 95% Global Average URE during operations at Zero AOD • ≤ 12.8m 95% Global Average URE during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1
Single-Frequency C/A-Code: • ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors
Single-Frequency C/A-Code: • ≤ 2 mm/sec^2 95% Global average URAE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors
Coordinated Universal Time Offset Error Accuracy	**Conditions and Constraints**
• ≤ 40 nanoseconds 95% Global average UTCOE during normal operations at Any AOD.	• For any healthy SPS SIS

5.1 Position Accuracy

The data used for this section was collected for every second from 1 January through 31 March 2015 at the selected WAAS locations. Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. Every twenty-four hour analysis period this quarter passed both the worst-case and global position accuracy requirements set forth by the SPS specification.

Table 5-1 Horizontal & Vertical Accuracy Statistics for the Quarter

Site	95% Vertical (Meters)	95% Horizontal (Meters)	99.99% Vertical (Meters)	99.99% Horizontal (Meters)
Albuquerque	4.185	2.285	7.966	4.853
Anchorage	5.403	2.321	10.665	5.264
Atlanta	4.090	2.696	8.539	6.564
Barrow	6.187	2.637	13.090	5.545
Bethel	5.603	2.282	10.957	4.983
Billings	4.071	2.181	8.096	6.716
Boston	4.004	2.651	10.092	5.052
Cleveland	4.035	2.597	8.462	4.738
Cold Bay	5.386	2.150	10.828	4.882
Fairbanks	5.508	2.422	11.135	4.945
Gander	3.998	2.416	10.304	6.946
Honolulu	7.321	9.023	15.550	14.556
Houston	4.319	2.742	8.129	8.187
Iqaluit	5.490	3.618	12.170	9.771
Juneau	4.603	2.264	10.189	5.615
Kansas City	4.217	2.507	8.898	5.316
Kotzebue	5.777	2.465	12.042	5.254
Los Angeles	4.629	2.168	8.704	5.710
Merida	5.119	3.937	17.324	11.364
Miami	4.348	3.111	9.948	8.668
Minneapolis	4.166	2.371	10.163	4.772
Oakland	4.806	2.182	8.844	4.824
Salt Lake City	4.261	2.191	8.462	5.503
San Jose Del Cabo	5.708	4.371	20.571	13.761
San Juan	8.362	6.378	21.778	17.879
Seattle	4.288	2.055	8.250	5.541
Tapachula	7.356	6.267	19.516	15.439
Washington, DC	4.087	2.700	8.447	5.382

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 January to 31 March 2015.

Figure 5-1 Global Vertical Error Histogram

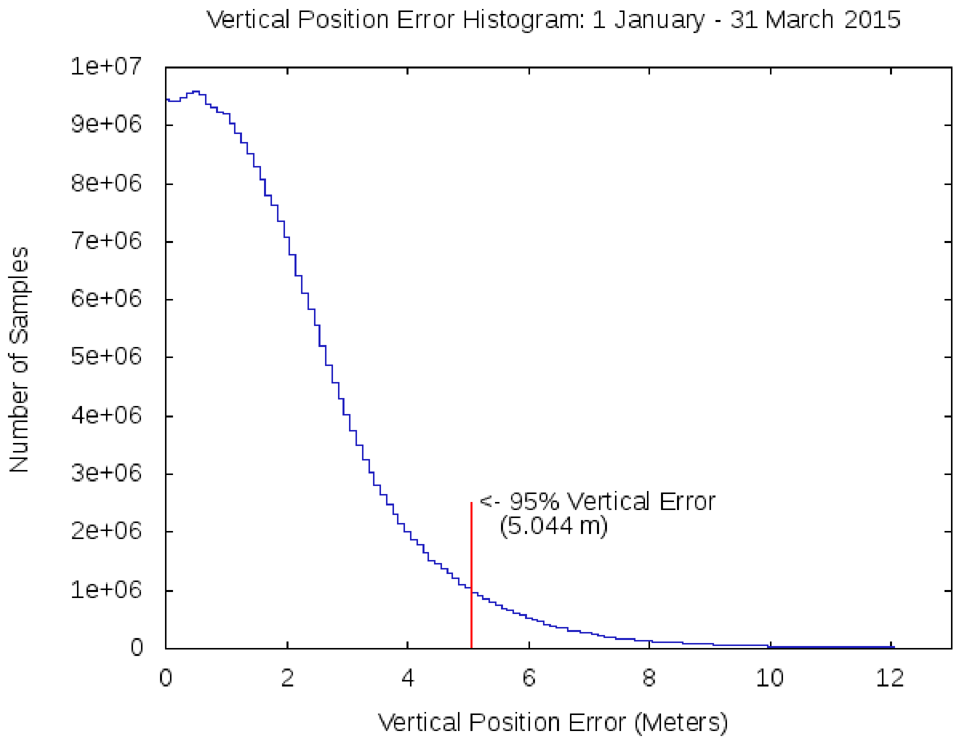
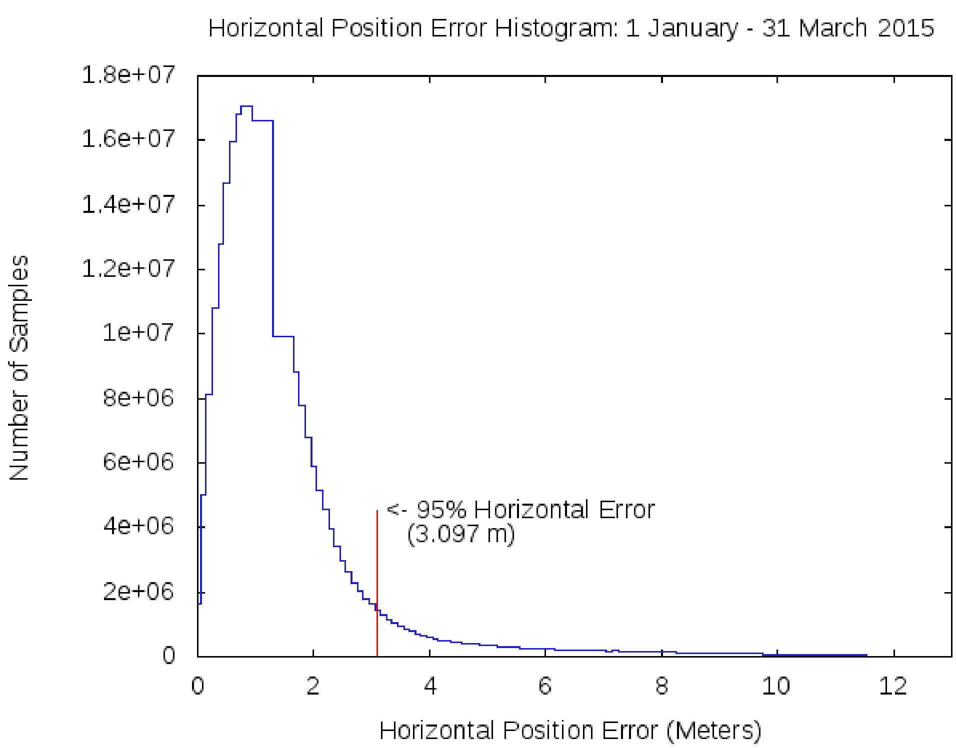


Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 2015 was downloaded from USNO Internet site. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Fig 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with one nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Fig 5-3. The maximum instantaneous UTC offset error (UTCOE) for the quarter was 47.9 nanoseconds. The mean, standard deviation and 95% index of Time Transfer Error, and the maximum UTCOE are all within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Error

5.3 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 January and 31 March 2015. A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-2 Range Error Statistics

(Meters)

PRN	RMS Range Error ($\leq$ 6 m)	Range Error Mean	1σ	95% Range Error	Max Range Error (SPS Spec. $\leq$ 30 m)	Samples
1	1.723	-0.078	1.533	3.331	17.748	13520538
2	2.148	1.144	1.652	4.172	20.123	14368664
3	2.128	-0.528	1.806	3.980	18.746	14148893
4	1.790	0.082	1.501	3.463	16.823	14106890
5	2.060	0.096	1.923	3.820	18.542	13452803
6	1.945	-0.315	1.762	3.781	19.663	13630052
7	2.381	-0.184	1.753	4.276	16.623	12519286
9	2.148	0.009	1.675	3.874	21.226	13251905
10	2.817	1.394	1.999	5.112	23.838	12059110
11	1.931	0.858	1.469	3.627	15.030	12267036
12	1.931	0.002	1.799	3.813	22.232	13894402
13	2.057	0.013	1.815	4.132	25.036	13313205
14	2.012	0.241	1.564	3.717	26.411	14103890
15	1.796	-0.004	1.565	3.417	20.634	12595863
16	2.098	0.629	1.631	3.955	18.793	13230362
17	2.273	0.415	1.952	4.305	19.552	14291573
18	1.839	0.611	1.275	3.304	19.709	13431154
19	2.006	1.199	1.391	3.751	17.160	12167405
20	2.525	1.011	1.933	4.620	20.861	13158590
21	1.922	0.819	1.341	3.577	19.179	12774752
22	2.255	1.146	1.410	3.891	17.261	12528536
23	2.221	-0.108	1.624	4.012	15.586	12692622
24	2.049	-0.558	1.691	3.877	18.131	13770924
25	1.669	0.160	1.474	3.268	14.722	14140347
26	1.603	0.529	1.348	3.070	9.065	725092
27	1.608	0.295	1.321	3.152	18.545	13082186
28	2.545	1.117	1.741	4.483	17.557	13522235
29	1.788	0.164	1.525	3.629	24.378	12732769
30	2.214	0.217	1.595	3.990	16.477	12510232
31	2.046	-0.197	1.587	3.813	17.065	13685230
32	2.060	0.716	1.468	3.664	17.209	12308322

Table 5-3 Range Rate Error Statistics

(Millimeters/ Second)

PRN	Range Rate Error RMS	95% Range Rate Error	Max Range Rate Error	Samples
1	2.177	3.310	231.500	13520538
2	2.015	3.410	195.560	14368664
3	2.220	3.449	165.510	14148893
4	2.329	3.386	212.120	14106890
5	2.032	3.339	198.480	13452803
6	1.967	3.282	203.460	13630052
7	2.056	3.365	154.390	12519286
9	2.058	3.360	172.840	13251905
10	2.199	3.488	149.340	12059110
11	2.113	3.414	220.780	12267036
12	2.304	3.733	252.650	13894402
13	2.091	3.539	192.620	13313205
14	2.284	3.567	204.270	14103890
15	2.005	3.283	169.400	12595863
16	2.177	3.431	152.270	13230362
17	2.062	3.461	202.780	14291573
18	2.028	3.274	240.070	13431154
19	1.929	3.187	159.910	12167405
20	2.066	3.405	184.400	13158590
21	2.069	3.379	171.700	12774752
22	2.218	3.240	168.850	12528536
23	2.177	3.348	180.990	12692622
24	2.380	3.582	310.130	13770924
25	2.151	3.283	240.310	14140347
26	1.941	3.053	83.720	725092
27	1.993	3.068	192.910	13082186
28	2.070	3.260	156.270	13522235
29	1.959	3.380	198.140	12732769
30	1.897	3.118	207.970	12510232
31	2.273	3.477	183.010	13685230
32	2.189	3.263	176.480	12308322

Table 5-4 Range Acceleration Error Statistics

(Micrometers/Second^2)

PRN	Range Acceleration Error RMS (μm/s^2)	95% Range Acceleration Error (μm/s^2)	Max Range Acceleration Error (μm/s^2)	Samples
1	16.858	24.218	2310	13520538
2	14.521	23.249	1950	14368664
3	17.305	25.364	1640	14148893
4	18.619	26.239	2130	14106890
5	15.084	25.252	1940	13452803
6	14.291	22.643	1960	13630052
7	15.579	24.909	1550	12519286
9	15.464	24.097	1720	13251905
10	16.583	24.450	1490	12059110
11	16.222	25.511	2210	12267036
12	16.952	28.038	2480	13894402
13	14.753	25.355	1920	13313205
14	17.829	27.617	2030	14103890
15	14.835	24.594	1720	12595863
16	17.304	26.785	1520	13230362
17	14.911	24.040	1990	14291573
18	15.842	26.032	2400	13431154
19	14.613	23.949	1570	12167405
20	15.742	24.600	1820	13158590
21	15.790	27.089	1690	12774752
22	18.019	26.691	1650	12528536
23	17.418	26.305	1800	12692622
24	18.858	28.798	3120	13770924
25	16.793	24.823	2400	14140347
26	14.269	24.883	840	725092
27	15.758	23.855	1930	13082186
28	15.731	23.080	1550	13522235
29	13.901	23.913	1980	12732769
30	14.155	22.435	2060	12510232
31	18.049	27.711	1820	13685230
32	17.704	26.429	1770	12308322

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. The highest maximum range error occurred on satellite 14 with an error of 26.411 meters. Satellite 26 had the lowest maximum range error of 9.065 meters.

Figure 5-4 Distribution of Daily Max Range Errors

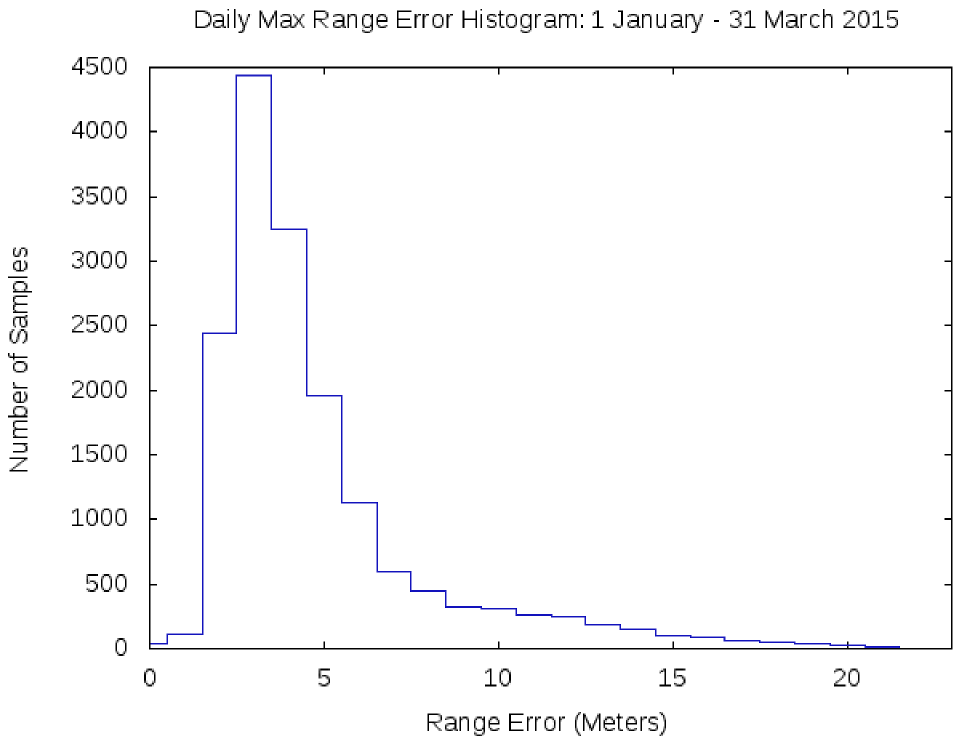


Figure 5-5 Distribution of Daily Max Range Rate Errors

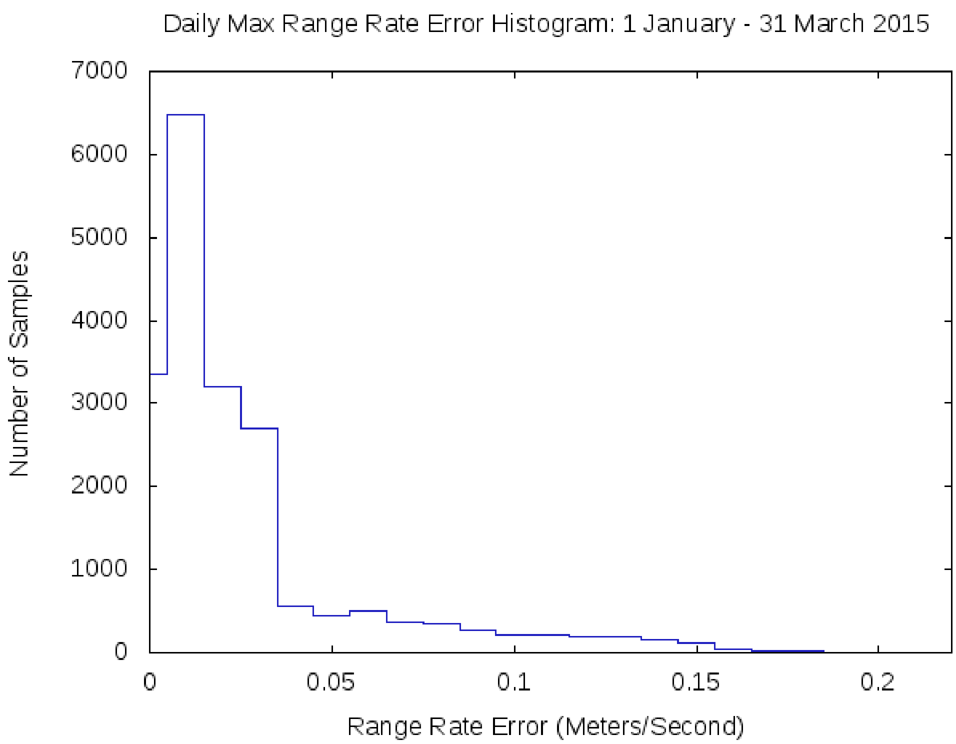


Figure 5-6 Distribution of Daily max Range Acceleration Errors

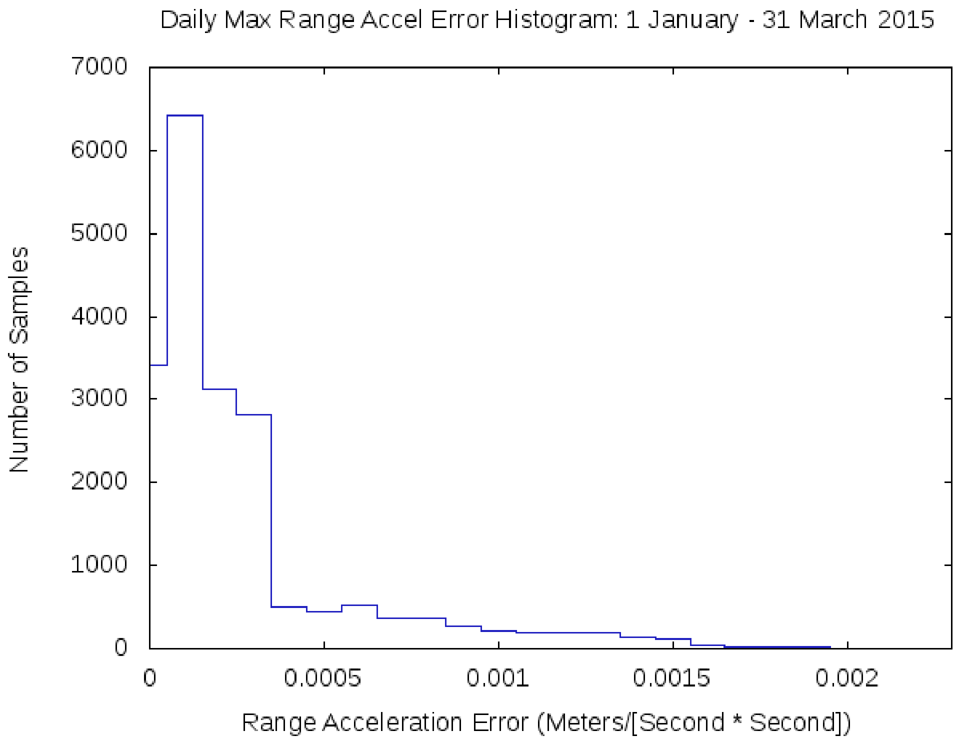


Figure 5-7 Range Error Histogram

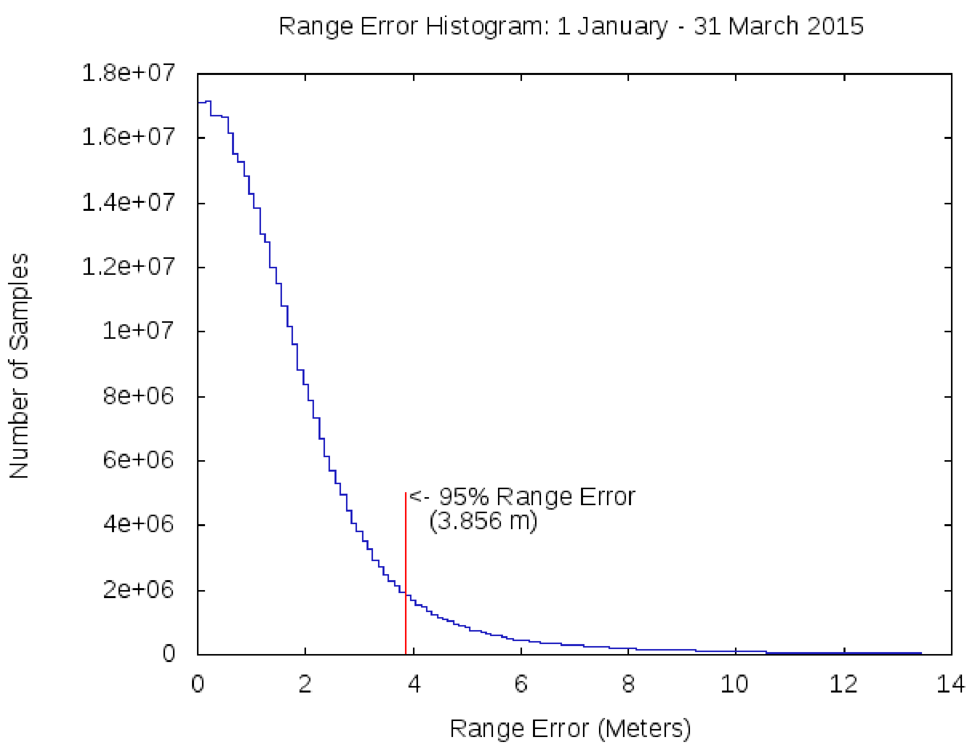


Figure 5-8 Maximum Range Error Per Satellite

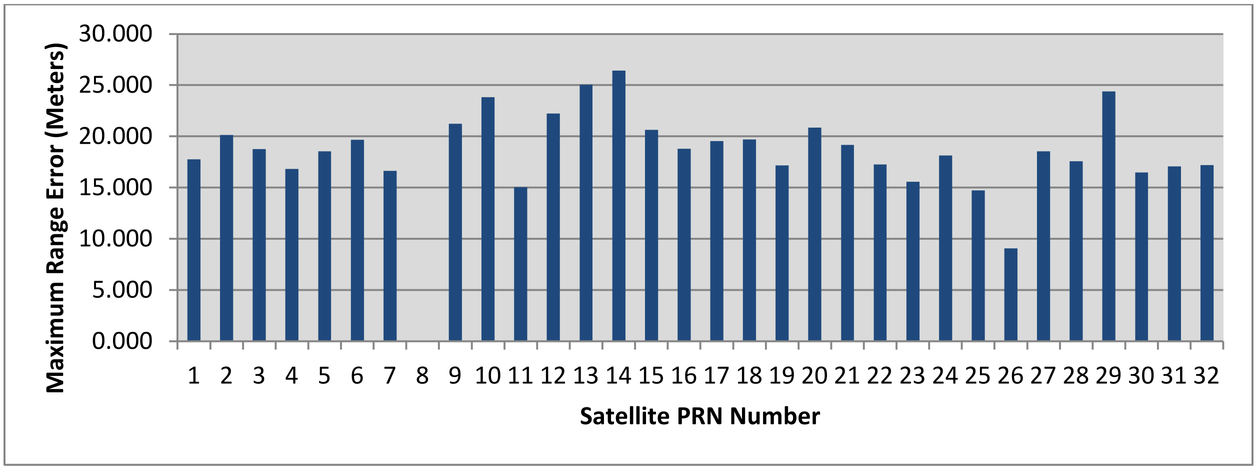


Figure 5-9 Maximum Range Rate Error Per Satellite

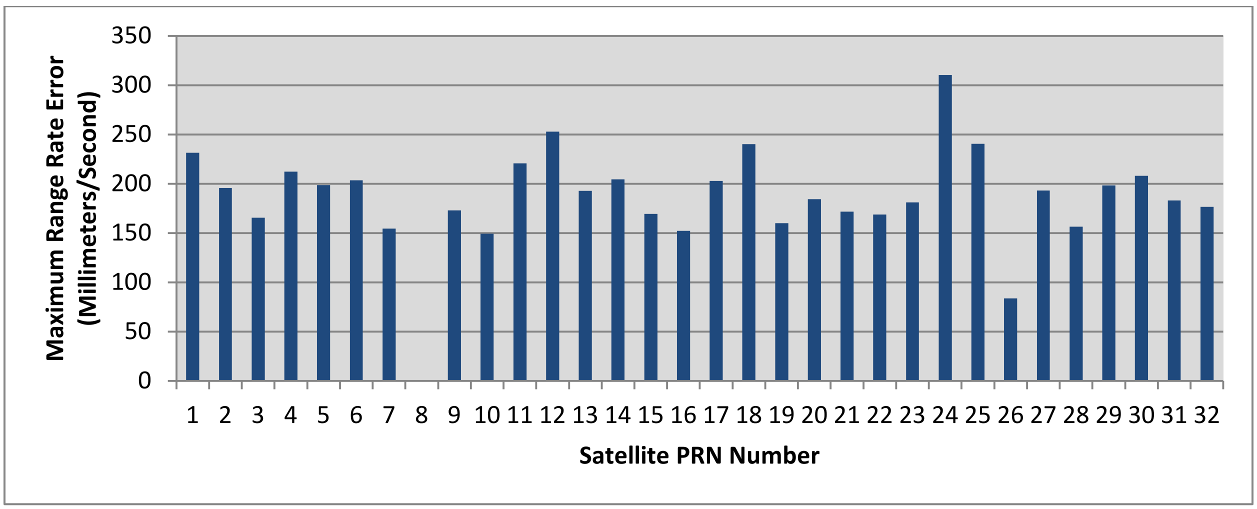
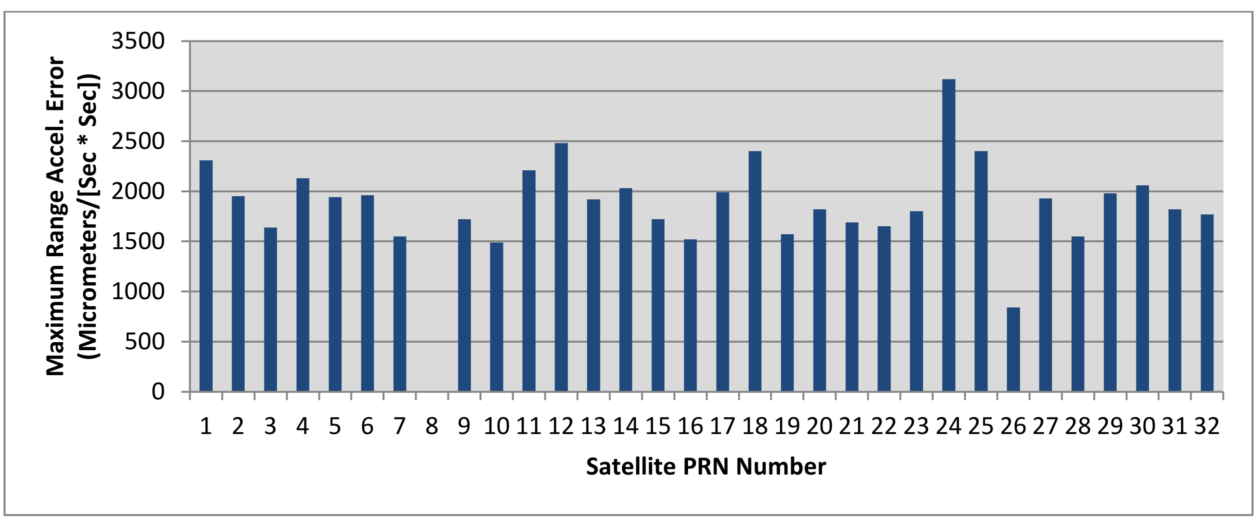


Figure 5-10 Maximum Range Acceleration Error Per Satellite



6 Solar Storms

Solar storm activity is being monitored in order to assess the possible impact on GPS SPS performance. Solar activity is reported by the Space Weather Prediction Center (SWPC), a division of the National Oceanic and Atmospheric Administration (NOAA). When storm activity is indicated, ionospheric delays of the GPS signal, satellite outages, position accuracy and availability will be analyzed.

The following article was taken from the SEC web site http://swpc.noaa.gov. It briefly explains some of the ideas behind the association of the aurora with geomagnetic activity and a bit about how the ‘K-index’ or ‘K-factor’ works.

> *The aurora is caused by the interaction of high-energy particles (usually electrons) with neutral atoms in the earth's upper atmosphere. These high-energy particles can ‘excite’ (by collisions) valence electrons that are bound to the neutral atom. The ‘excited’ electron can then ‘de-excite’ and return back to its initial, lower energy state, but in the process it releases a photon (a light particle). The combined effect of many photons being released from many atoms results in the aurora display that you see.*
>
> *The details of how high energy particles are generated during geomagnetic storms constitute an entire discipline of space science in its own right. The basic idea, however, is that the Earth’s magnetic field (let us say the ‘geomagnetic field’) is responding to an outwardly propagating disturbance from the Sun. As the geomagnetic field adjusts to this disturbance, various components of the Earth’s field change form, releasing magnetic energy and thereby accelerating charged particles to high energies. These particles, being charged, are forced to stream along the geomagnetic field lines. Some end up in the upper part of the earth’s neutral atmosphere and the auroral mechanism begins.*
>
> *An instrument called a magnetometer may also measure the disturbance of the geomagnetic field. At NOAA’s operations center magnetometer data is received from dozens of observatories in one-minute intervals. The data is received at or near to ‘real-time’ and allows NOAA to keep track of the current state of the geomagnetic conditions. In order to reduce the amount of data NOAA converts the magnetometer data into three-hourly indices, which give a quantitative, but less detailed measure of the level of geomagnetic activity. The K-index scale has a range from 0 to 9 and is directly related to the maximum amount of fluctuation (relative to a quiet day) in the geomagnetic field over a three-hour interval.*
>
> *The K-index is therefore updated every three hours. The K-index is also necessarily tied to a specific geomagnetic observatory. For locations where there are no observatories, one can only estimate what the local K-index would be by looking at data from the nearest observatory, but this would be subject to some errors from time to time because geomagnetic activity is not always spatially homogenous.*
>
> *Another item of interest is that the location of the aurora usually changes geomagnetic latitude as the intensity of the geomagnetic storm changes. The location of the aurora often takes on an ‘oval-like’ shape and is appropriately called the auroral oval.*

Figures 6-1 through 6-3 show the K-index for three time periods with significant solar activity. Although there were other days with increased solar activity, these time periods were selected as examples. (See Appendix B for the actual geomagnetic data for this reporting period.)

Figure 6-1 K-Index for 17-19 March 2015

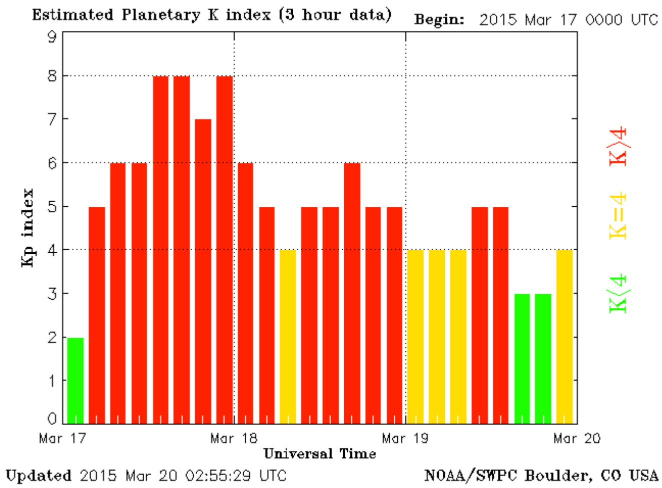


Figure 6-2 K-Index for 6-8 January 2015

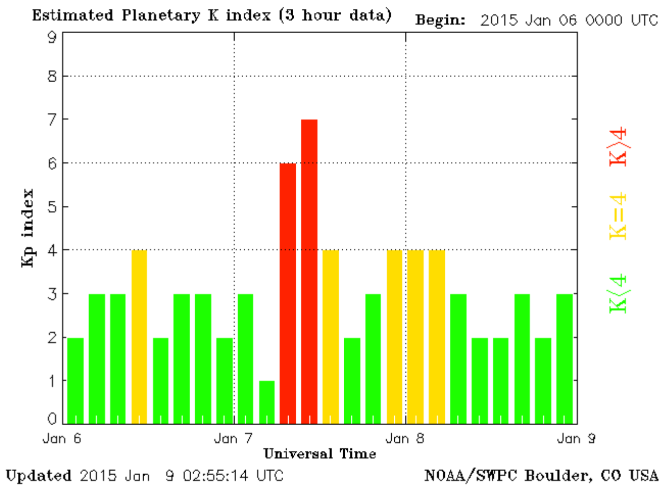


Figure 6-3 K-Index for 28 February-2 March 2015

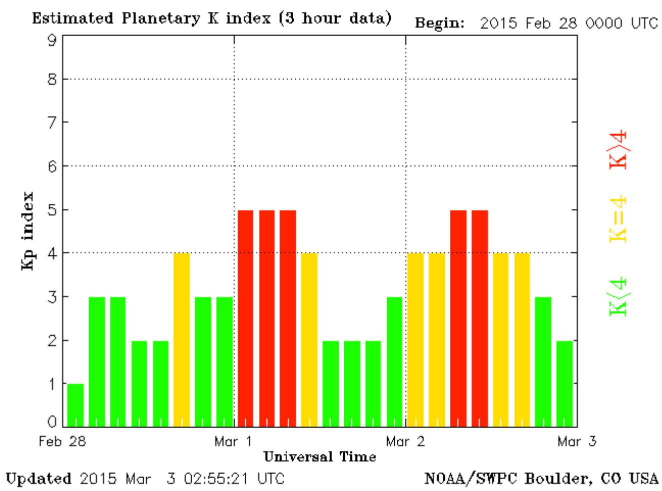


Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for March 17, 2015

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Maximum Horizontal (Meters)	Maximum Vertical (Meters)
Albuquerque	3.009	6.441	5.279	7.645
Anchorage	2.643	5.898	3.964	7.223
Atlanta	5.036	6.324	7.098	7.425
Barrow	2.613	5.175	3.287	8.065
Bethel	2.655	5.848	3.834	6.554
Billings	2.368	6.818	3.409	8.380
Boston	3.536	5.760	4.947	12.281
Cleveland	2.997	7.606	4.124	9.166
Cold Bay	2.452	6.382	3.181	7.639
Fairbanks	2.467	5.674	3.860	8.395
Gander	5.082	3.576	5.856	6.039
Honolulu	8.202	5.898	10.634	10.795
Houston	5.495	6.136	8.944	8.246
Iqaluit	2.713	3.528	4.813	6.314
Juneau	2.626	5.308	3.273	7.379
Kansas City	2.617	8.014	3.445	9.094
Kotzebue	2.484	5.760	3.398	8.389
Los Angeles	3.626	6.481	5.849	8.745
Merida	8.118	4.323	9.199	7.301
Miami	5.881	5.198	8.869	6.787
Minneapolis	2.566	8.119	3.843	10.719
Oakland	2.830	6.724	4.451	7.870
Salt Lake City	2.248	7.207	3.198	8.545
San Jose Del Cabo	8.478	3.828	9.600	7.349
San Juan	6.588	9.254	9.105	12.285
Seattle	2.271	6.435	3.442	7.555
Tapachula	8.169	5.884	9.959	10.731
Washington, DC	4.686	6.991	5.519	8.806

7 IGS Analysis

GPS SPS accuracy performance was evaluated at a selection of high rate IGS stations(1). The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products.

Sites with high data rate (1 Hz) with good availability which are outside of the WAAS service area that also provide a good geographic distribution have been selected. The 3 Russian Federation sites, MOBN, NRIL, and PETS, have not yet been returned to service. To facilitate differentiating between GPS accuracy issues and receiver tracking problems, an automatic data screening function excluded errors greater than 500 meters and or times when VDOP or HDOP were greater than 10. The remaining receiver tracking issues are still included in the processing and are forced into the 50.1 meter histogram bin. These issues cause the outliers seen in the 99.99% statistics and are visible in the 95% accuracy trend plots.

Equatorial sites experienced higher than normal errors this quarter due to increased errors in the Klobuchar ionosphere model used by single frequency SPS receivers to correct for ionosphere delay errors. The errors are due to increased solar activity and the seasonal tilt of the earth's axis with respect to the sun. Figures 7-4 and 7-5 shows an example of the impact of the poor Klobuchar model performance at the MASI site for an example day. Figures 7-6 and 7-7 shows the USUD outlier visible in Figure 7-2 for day 11. The day 11 USUD event also appears to be the result of the performance of the Klobuchar ionosphere model.

High quality broadcast navigation data and Klobuchar model data is created by voting across all available IGS high rate RINEX navigation data. Some manual review was necessary to recover missing navigation data where the number of IGS sites reporting navigation data was below the voting threshold (i.e. 4).

Table 7.1 and Figure 7-1 show the IGS site information and locations. The Russian Federation sites were unavailable for this reporting period. Table 7.2 shows the GPS SPS Accuracy Performance observed at a selection of High Rate IGS sites. Figure 7-2 shows the 95% horizontal accuracy trends at these sites. Figure 7-3 shows the 95% vertical accuracy trends at these sites. A value of zero indicates no data. The ramping error in the trend plots for the equatorial sites is due to seasonal variations in the ionosphere that cannot be corrected by the Klobuchar thin shell model of the ionosphere utilized by single frequency GPS SPS receivers.

(1) J.M. Dow, R.E. Neilan, G. Gendt, "The International GPS Service (IGS): Celebrating the 10th Anniversary and Looking to the Next Decade," Adv. Space Res. 36 vol. 36, no. 3, pp. 320-326, 2005. Doi: 10.1016/j.asr.2005.05.125

Table 7-1 Selected IGS Site Information

ID	City	Country
BOGT	Bogota	Columbia
GLPS	Puerto Ayora	Ecuador
GUAM	Dededo	Guam
IISC	Bangalore	India
KIRU	Kiruna	Sweden
KOUR	Kourou	French Guyana
MADR	Robledo	Spain
MAL2	Malindi	Kenya
MAS1	Maspalomas	Spain
MATE	Matera	Italy
MOBN*	Obninsk	Russian Federation
NNOR	New Norcia	Australia
NRIL*	Norilsk	Russian Federation
PETS*	Petropavlovsk-Kamchatka	Russian Federation
POL2	Bishkek	Kyrghyzstan
SUTM	Sutherland	South Africa
TIDB	Tidbinbilla	Australia
UNSA	Salta	Argentina
USUD	Usuda	Japan

Figure 7-1 Selected IGS Site Locations

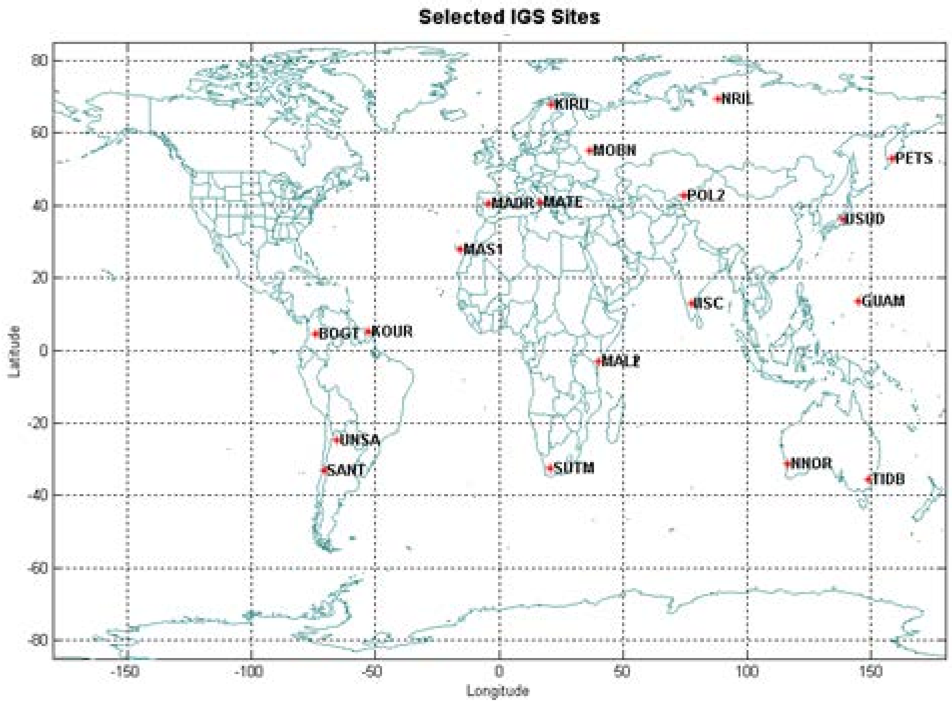


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
BOGT	8.03	10.86	22.77	44.90	97.79%
GLPS	5.43	7.39	14.87	24.12	89.74%
GUAM	3.98	9.00	9.58	17.09	95.38%
IISC	4.71	8.36	14.15	33.35	98.12%
KIRU	2.74	5.49	6.35	12.20	99.999%
KOUR	7.29	9.20	14.17	24.33	99.94%
MADR	3.75	4.98	16.33	20.78	96.24%
MAL2	4.62	5.97	13.08	18.08	94.55%
MAS1	11.67	10.13	21.12	40.04	99.93%
MATE	2.99	4.61	14.11	14.93	45.51%
MOBN	--	--	--	--	N/A
NNOR	2.94	4.86	6.69	16.50	99.99%
NRIL	--	--	--	--	N/A
PETS	--	--	--	--	N/A
POL2	2.21	5.47	13.22	17.74	93.83%
SANT	6.27	6.68	11.33	13.55	47.92%
SUTM	2.65	5.00	5.55	9.31	94.35%
TIDB	2.31	4.01	5.74	24.70	99.27%
UNSA	6.69	9.26	27.57	44.24	58.66%
USUD	5.06	6.04	19.82	28.93	99.83%

Figure 7-2 GPS SPS 95% Horizontal Accuracy Trends at Selected IGS Sites

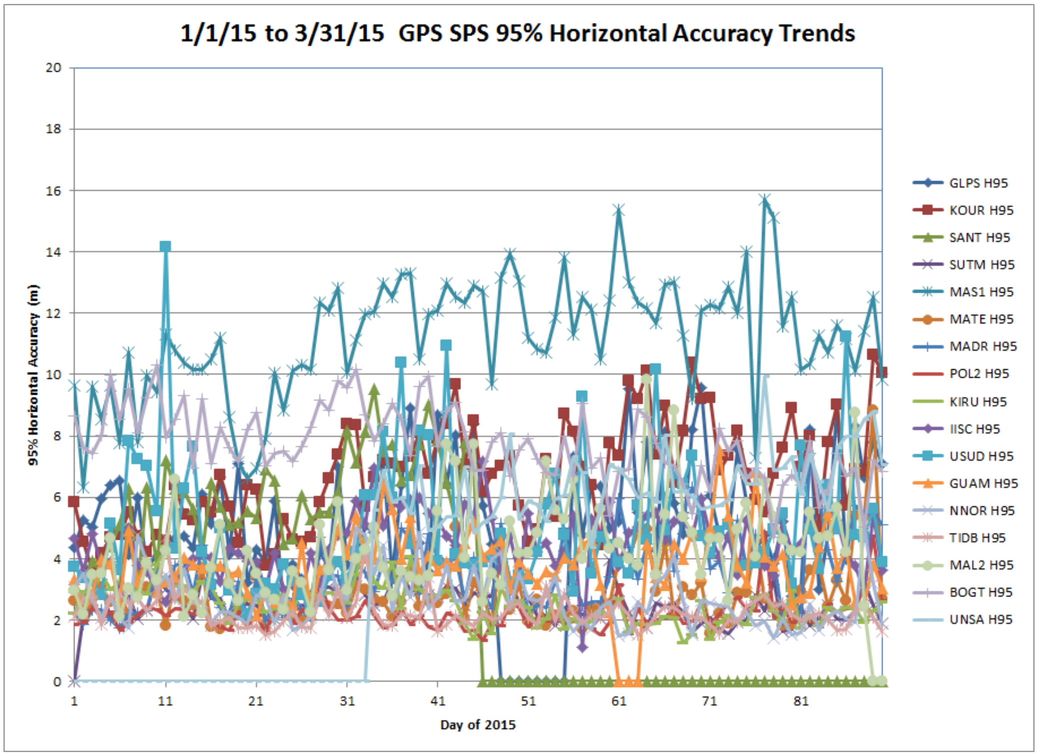


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites

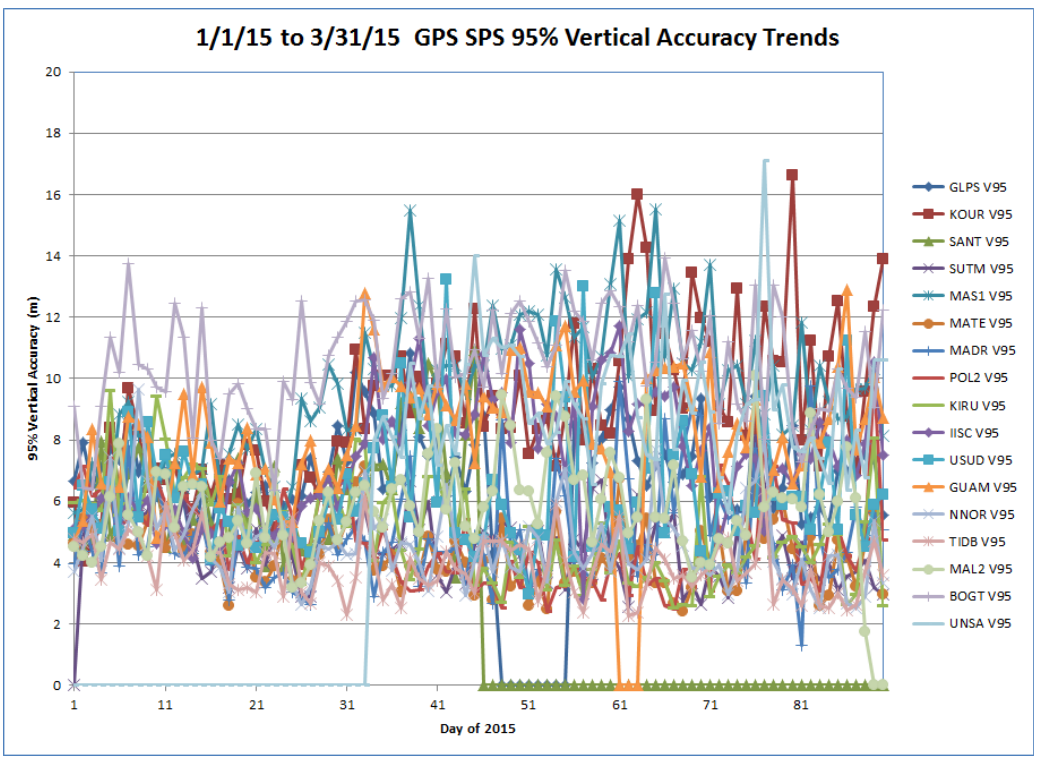


Figure 7-4 MASI Example Using Klobuchar Model

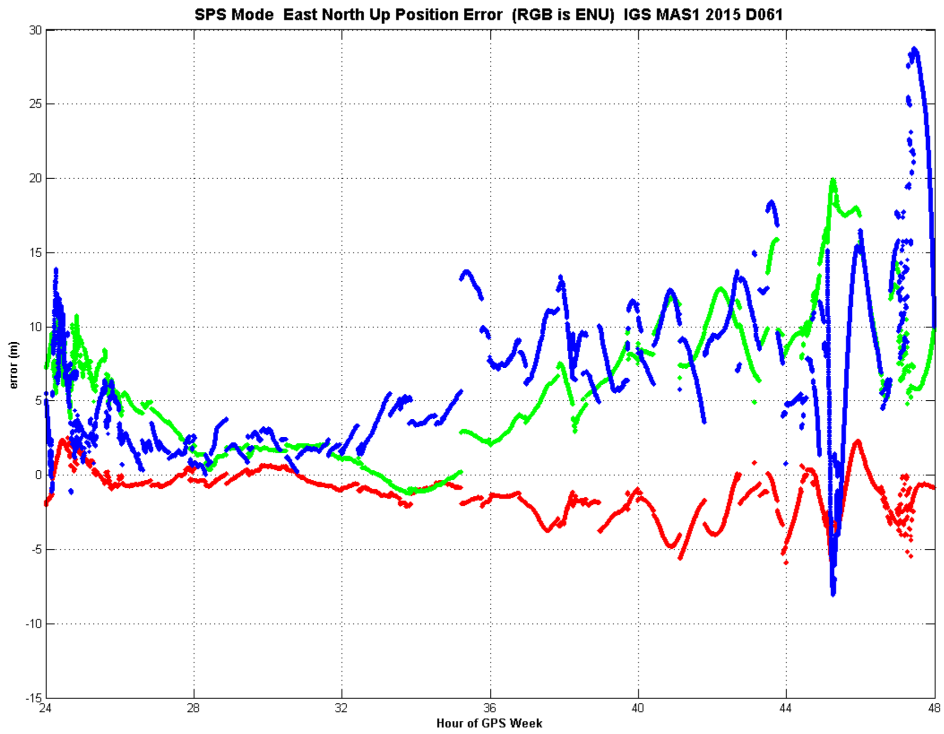


Figure 7-5 MASI Example Using Dual Frequency Measurements

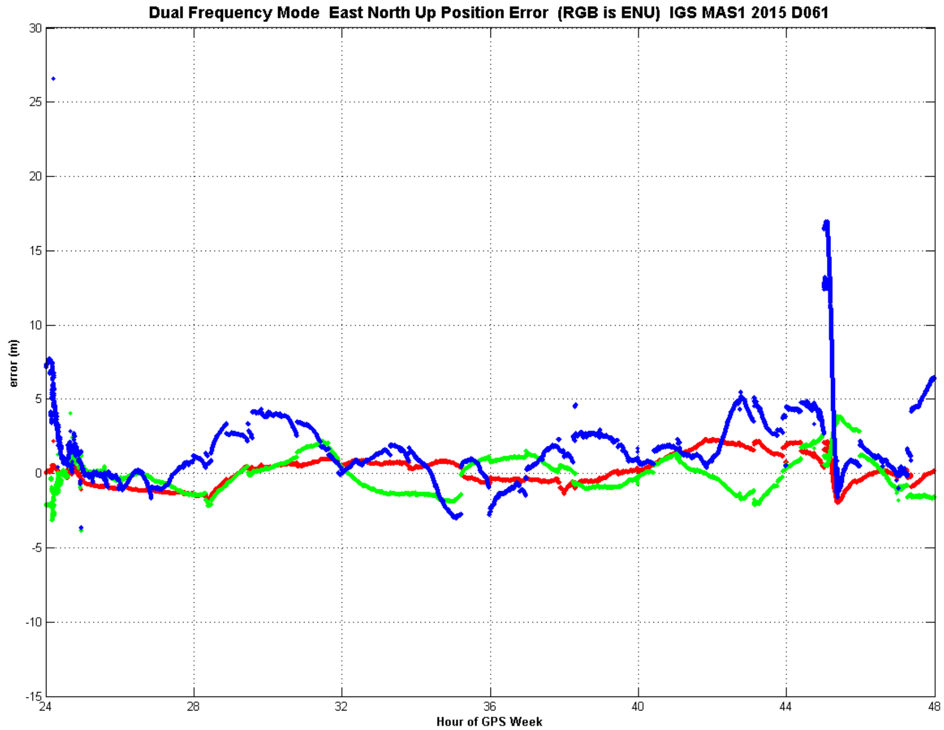


Figure 7-6 USUD 1/11/15 Outlier (using Klobuchar Model)

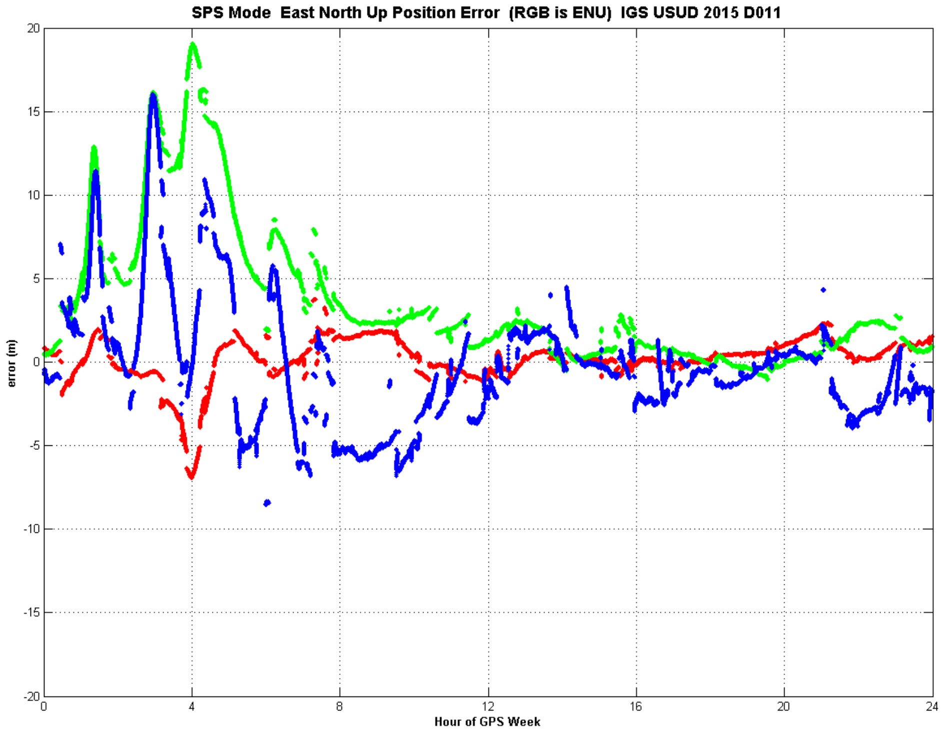
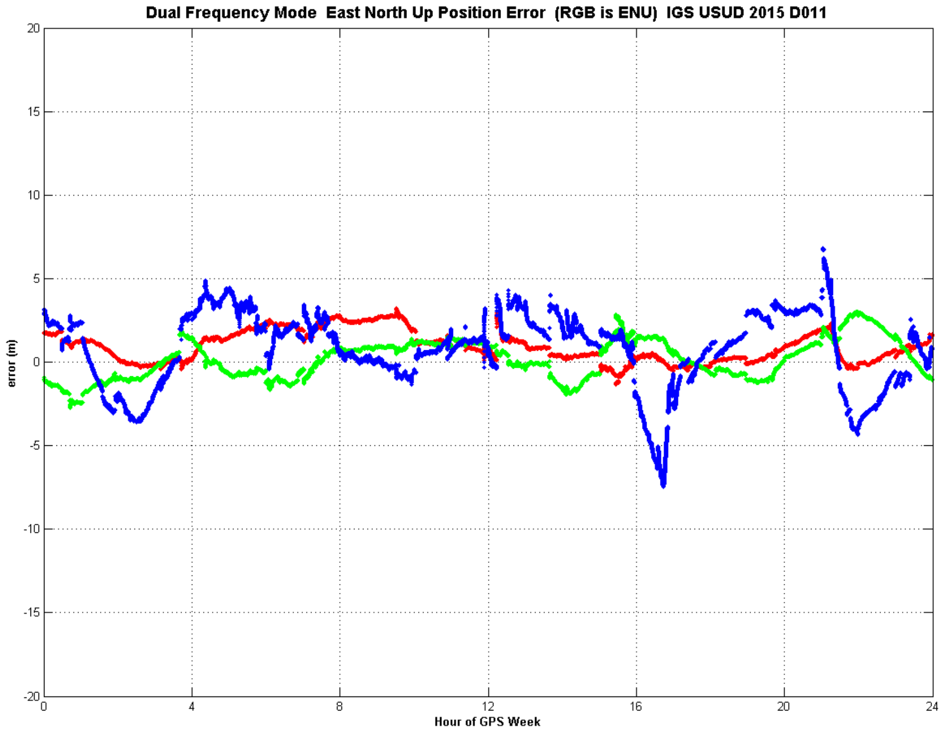


Figure 7-7 USUD 1/11/15 Outlier (using Dual Frequency Measurments)



8 RAIM Performance

Receiver autonomous integrity monitoring (RAIM) is a technology developed to assess the integrity of GPS signals in a GPS receiver system. It is especially important in safety critical GPS applications, such as aviation. In order for a GPS receiver to perform RAIM or fault detection (FD) function, a minimum of five visible satellites with satisfactory geometry must be visible. RAIM has various kinds of implementations; one of them performs consistency checks between all position solutions obtained with various subsets of the visible satellites. The receiver provides an alert to the pilot if the consistency checks fail.

Availability is a performance indicator of the RAIM algorithm. Availability is a function of the geometry of the constellation in view and of other environmental conditions. All the analysis performed here is utilizing the "Fault-Detection with no baro-aiding and SA off" RAIM implementation. Additional modes will be assessed at a future date. The test statistic used is a function of the pseudorange measurement residual (the difference between the expected measurement and the observed measurement) and the amount of redundancy. The test statistic is compared with a threshold value, and is determined based on the requirements for the probability of false alarm (Pfa), the probability of missed detection (Pmd), and the expected measurement noise. In aviation systems, the Pfa is fixed at 1/15000.

The horizontal protection limit (HPL) is a figure which represents the radius of a circle centered on the GPS position solution and is guaranteed to contain the true position of the receiver to within the specifications of the RAIM scheme (i.e. meets the Pfa and Pmd). The HPL is calculated as a function of the RAIM threshold and the satellite geometry at the time of the measurement. The HPL is compared with the horizontal alarm limit (HAL) to determine if RAIM is available. The RNP values shown here are measured in nautical miles, the computed HPL must be less than the RNP value for the service to be available.

8.1 Site Performance

Table 8-1 shows the RAIM performance for the twenty-eight sites evaluated. For all sites collected, the minimum percent of time in RNP 0.1 mode was 99.17% at Honolulu, Hawaii. The minimum percent of time spent in RNP 0.3 mode was 99.99% at Seattle, Washington. The maximum 99% HPL value was 205.578 meters at Billings, Montana.

Table 8-1 RAIM Site Statistics

CITY	99% HPL	Percent RNP 0.1	Percent RNP 0.3
Albuquerque	132.047	99.99	100.00
Anchorage	166.055	99.93	100.00
Atlanta	131.527	99.65	100.00
Barrow	120.422	100.00	100.00
Bethel	150.898	99.96	100.00
Billings	122.009	99.75	100.00
Boston	151.844	99.95	100.00
Cleveland	174.286	99.42	100.00
Cold Bay	205.578	98.64	100.00
Fairbanks	130.938	99.97	100.00
Gander	132.571	99.99	100.00
Honolulu	162.266	99.56	100.00
Houston	145.366	99.66	100.00
Iqaluit	173.419	99.63	100.00
Juneau	149.040	99.32	100.00
Kansas City	98.482	99.99	100.00
Kotzebue	150.859	99.92	100.00
Los Angeles	148.699	99.96	99.99
Merida	121.467	99.85	100.00
Miami	171.527	99.26	100.00
Minneapolis	123.699	99.99	100.00
Oakland	89.786	99.99	100.00
Salt Lake City	98.223	99.99	100.00
San Jose Del Cabo	136.310	99.77	100.00
San Juan	132.570	99.98	100.00
Seattle	138.237	99.87	100.00
Tapachula	97.514	100.00	100.00
Washington DC	110.096	99.99	100.00

8.2 RAIM Coverage

Figures 8-1 through 8-2 show the world wide RAIM coverage for both RNP 0.1 and RNP 0.3 respectively. Figures 8-3 through 8-4 show the daily RAIM coverage trends between 1 January and 31 March 2015.

Figure 8-1 RAIM RNP 0.1 Coverage

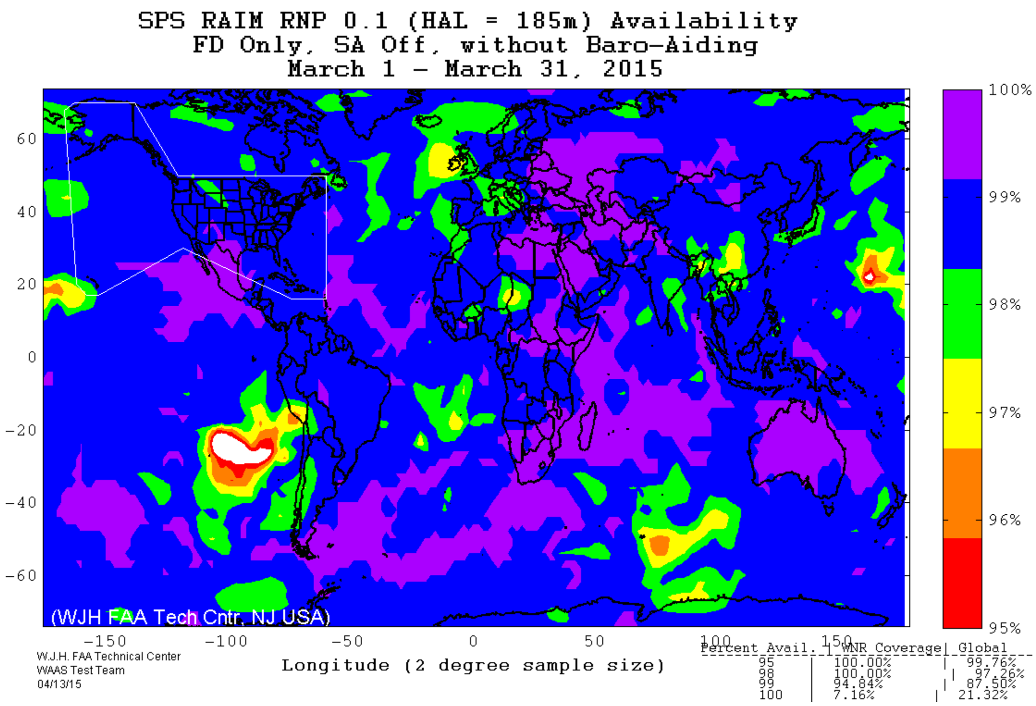


Figure 8-2 RAIM RNP 0.3 Coverage

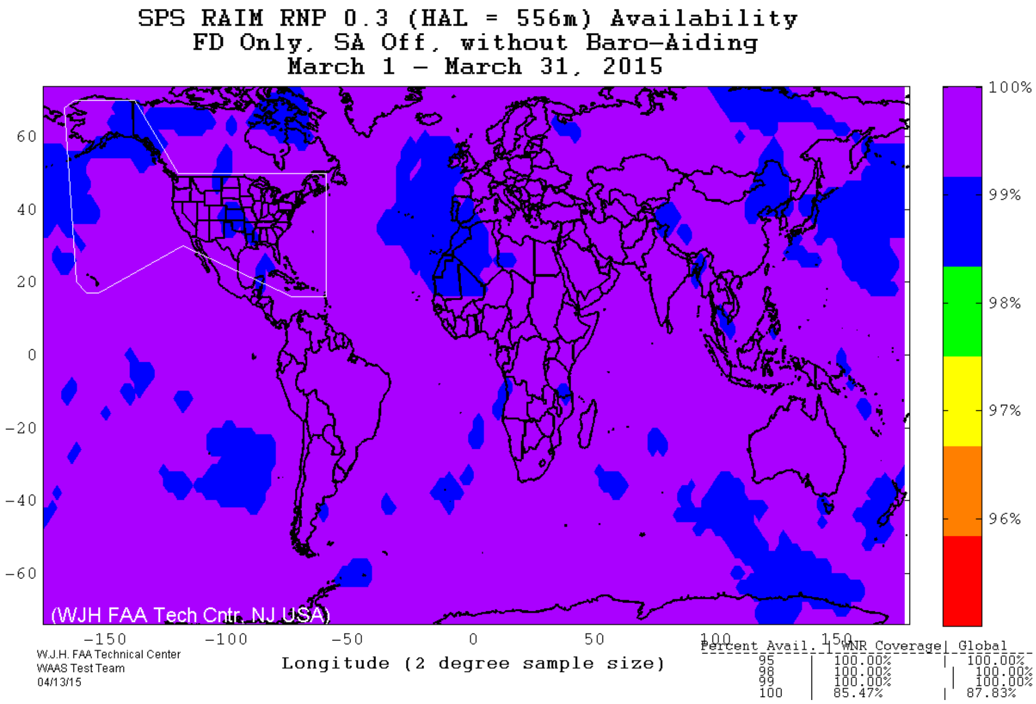


Figure 8-3 RAIM World Wide Coverage Trend

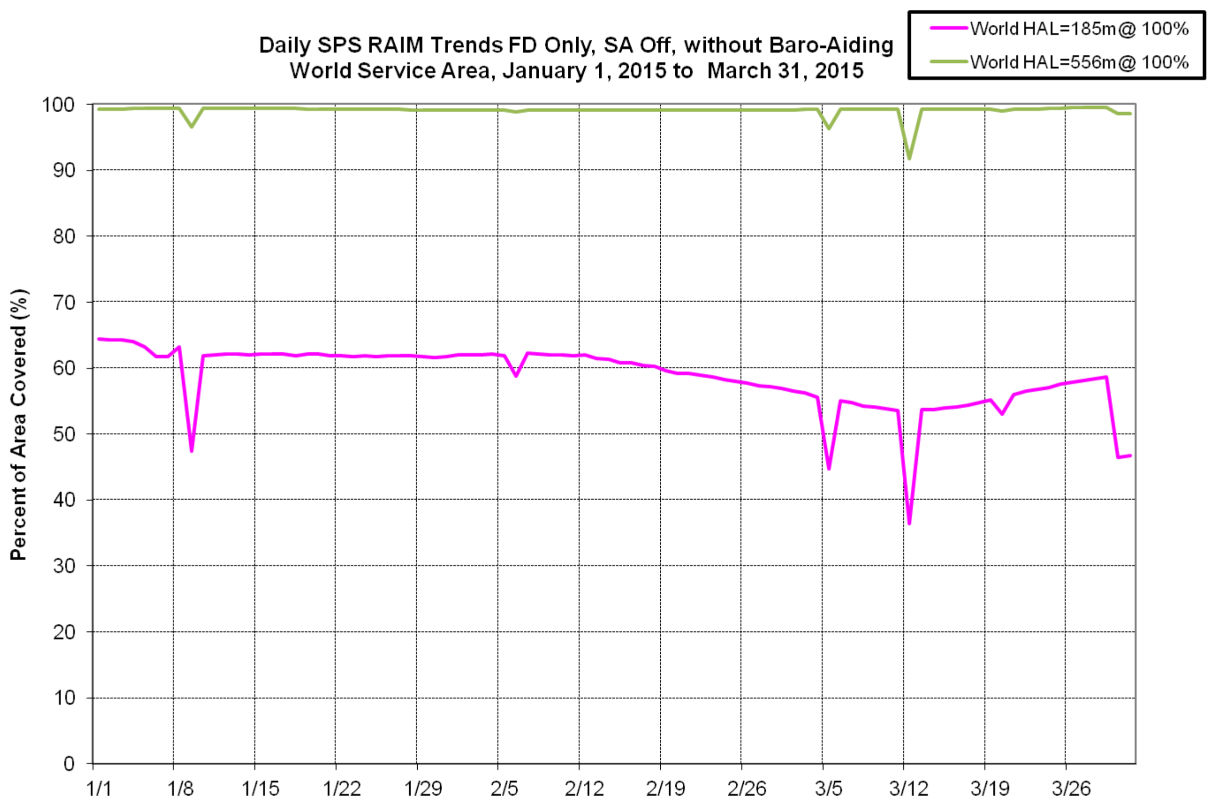
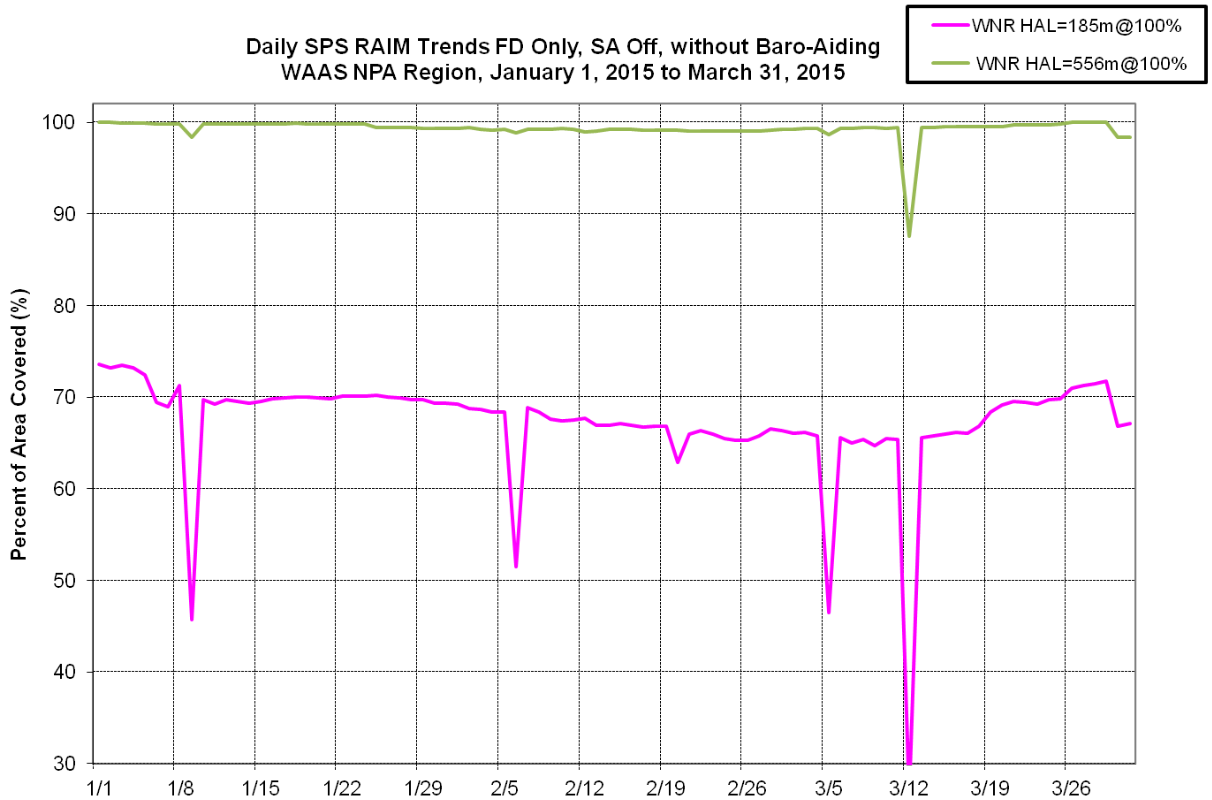


Figure 8-4 RAIM RNP Coverage Trend for WAAS NPA Service Area



8.3 RAIM Airport Analysis

Figures 8-5 and 8-6 shows RAIM RNP 0.1 and RNP 0.3 availability at all U.S. and Canadian airports that have an RNAV (GPS) published approach or better.

Figure 8-5 RAIM RNP 0.1 Airport Availability

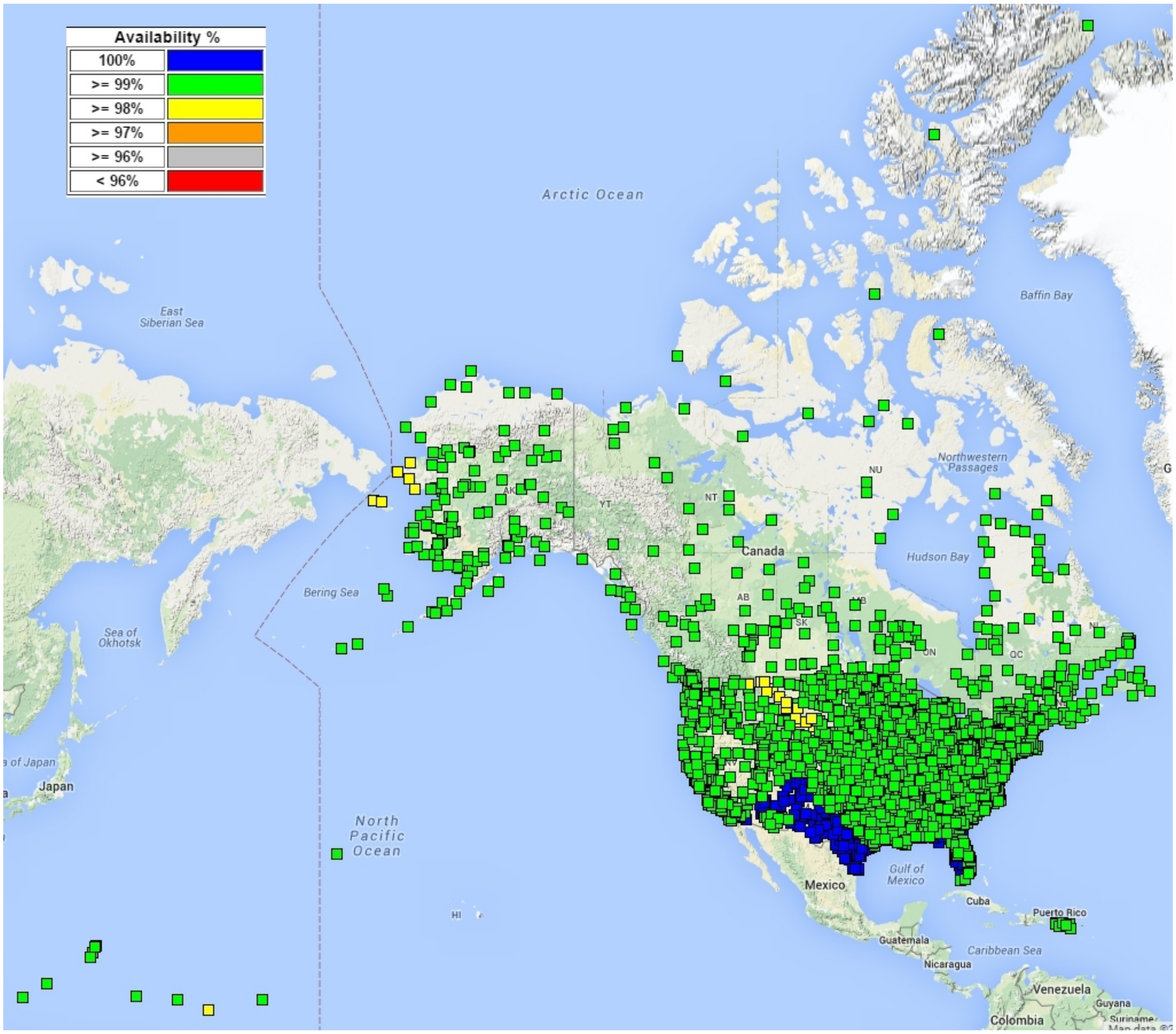
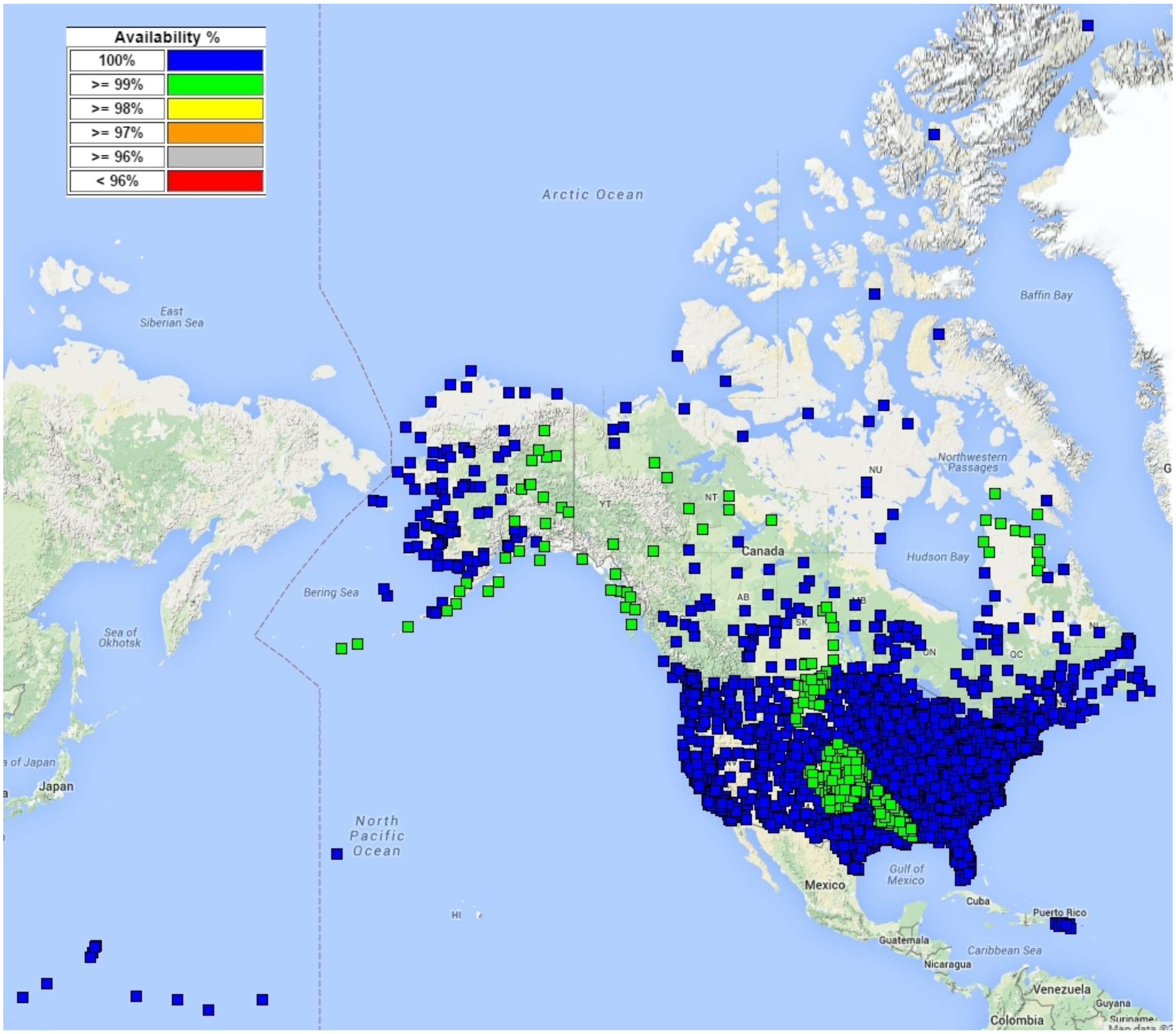


Figure 8-6 RAIM RNP 0.3 Airport Availability



Figures 8-7 and 8-8 respectively show the number of RAIM RNP 0.1 and RAIM RNP 0.3 outages for every airport in the U.S. and Canada that have a RNAV (GPS) published approach or better.

Figure 8-7 RAIM RNP 0.1 Airport Outages

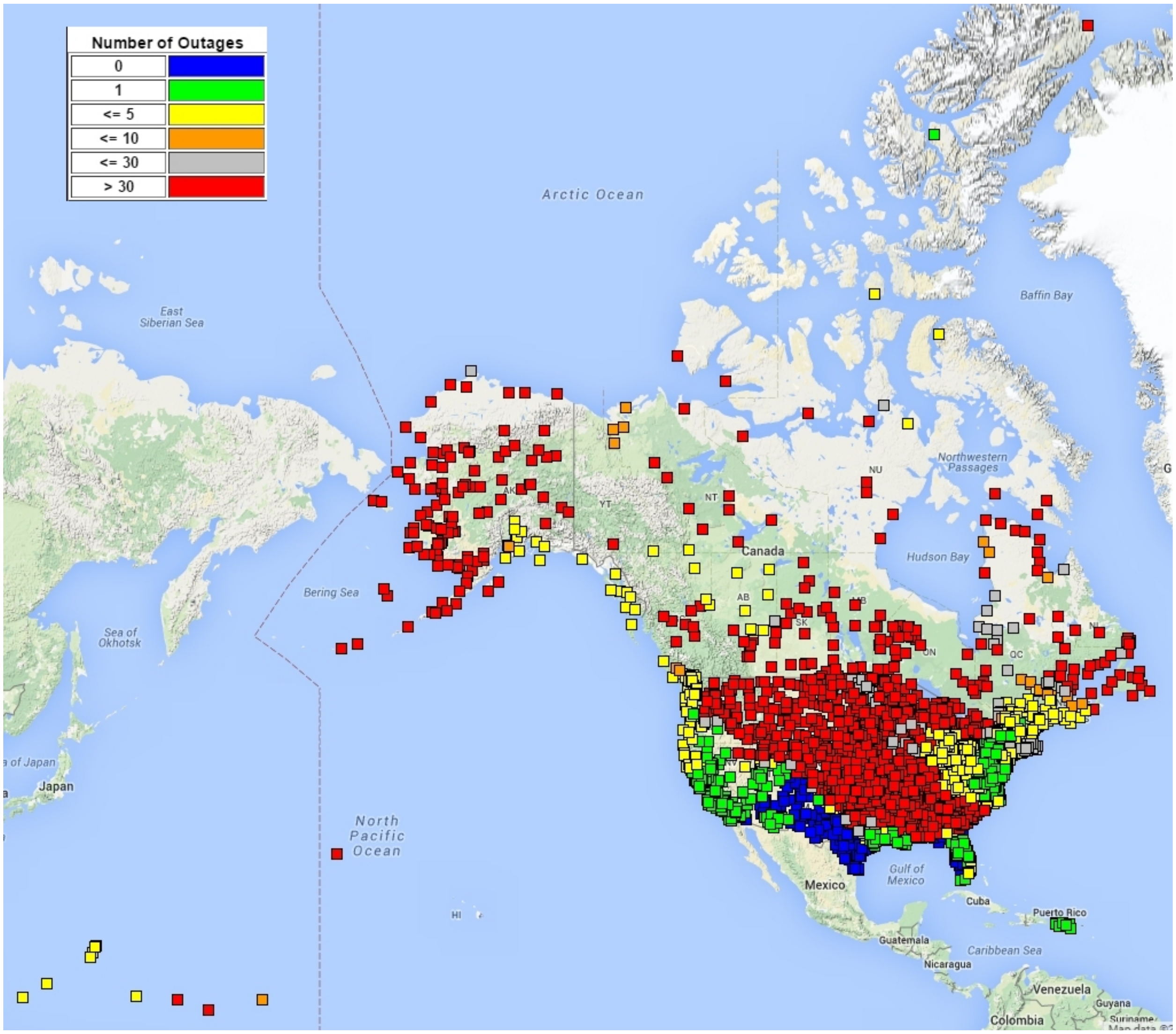
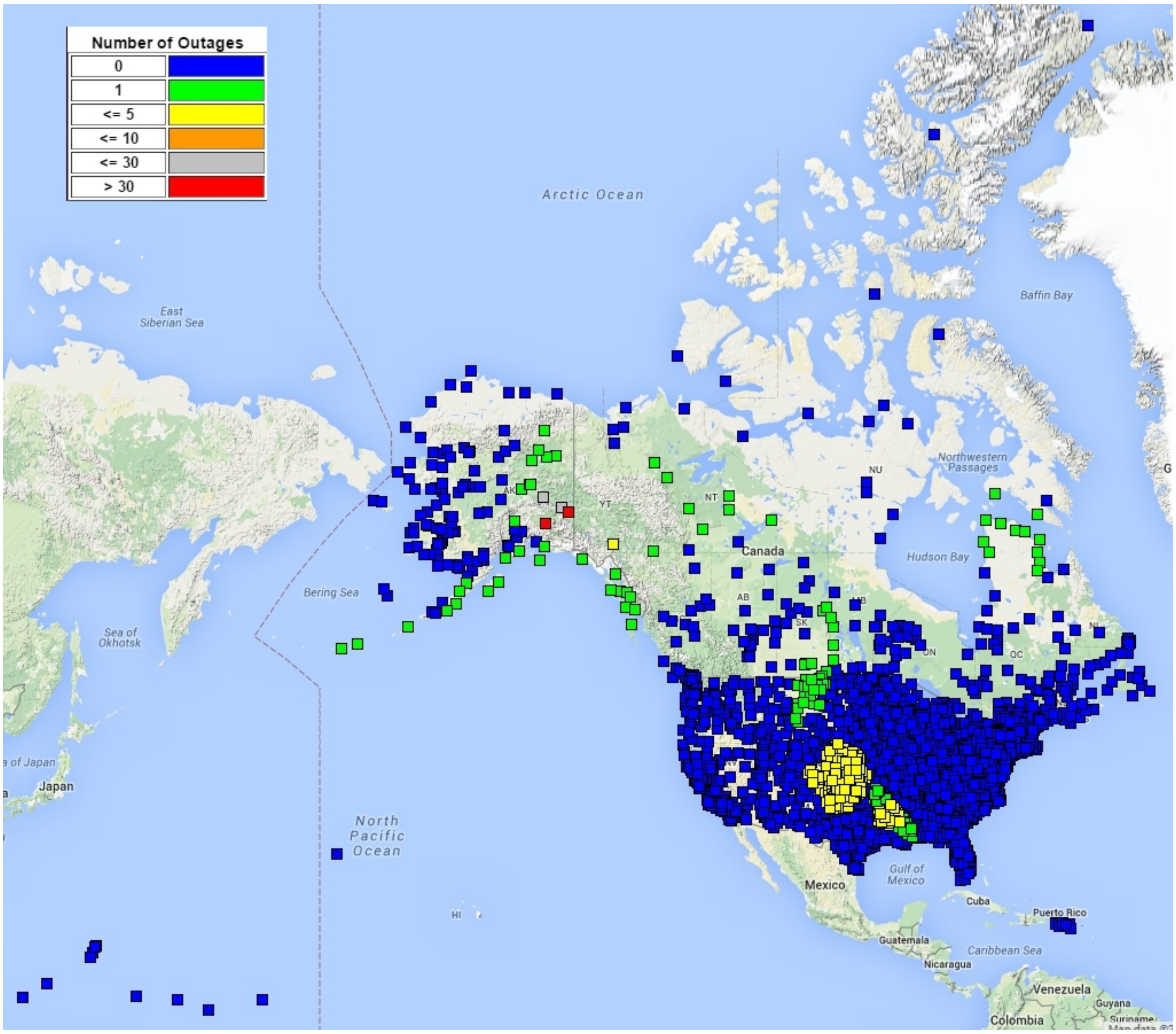


Figure 8-8 RAIM RNP 0.3 Airport Outages



9 GPS test NOTAMs Summary

GPS test NOTAM: Global Positioning System test Notices to Airmen - GPS test NOTAMs are issued in the event that GPS is predicted to be unreliable and/or unavailable at a defined location for specific times, as indicated in the NOTAM, due to scheduled testing events.

Status and Problem Reporting	Conditions and Constraints
Scheduled event affecting service • Appropriate GPS Test NOTAM issued to the FAA at least 5 hours prior to the event	• For any SPS SIS

9.1 GPS test NOTAMs issued for this reporting period

GPS test NOTAMs were tracked and trended from GPS test NOTAMs posted on the FAA PilotWeb website (https://pilotweb.nas.faa.gov/PilotWeb/). During this reporting period, January 1 through March 31 2015, there were a total 38 of GPS test NOTAMs. The total number of days affected in this reporting period is 51. Tables 9-1 and 9-2 below list the statistics of areas affected and durations.

Table 9-1 GPS test NOTAM durations

Cumulative duration	192.25 hours
Minimum duration	1.50 hours
Median duration	4.00 hours
Average duration	5.06 hours
Maximum duration	9.50 hours

Table 9-2 GPS test NOTAM affected areas (square miles) by altitude

	40,000 feet	25,000 feet	10,000 feet	4,000 feet	50 feet
Minimum	194,107	125,960	50,341	47,632	44,999
Average	919,545	750,726	527,505	449,965	395,954
Maximum	1,231,209	1,094,886	838,739	603,926	578,831

9.2 Tracking and trending of GPS test NOTAMs

The GPS Test NOTAMs that are tracked and trended for this reporting period were done with a specialized software analysis tool that is designed to not only trend but also archive GPS Test NOTAMs. It is designed to trend archived GPS Test NOTAMs for any specified time frame. In addition to the data provided in this report, this tool provides all data presented here along with airports with affected procedures via a web interface. The web interface is available at the following URL: http://waas.faa.gov/static/sog/notam/index.html.

The five plots below illustrate a visual depiction of the affected areas at their corresponding altitudes along with the impacted RNAV routes (indicated in red). Note that some GPS Test NOTAMs occupy the same area and position but differ in effective dates and/or durations.

Figure 9-1 GPS Test NOTAMs @ FL400

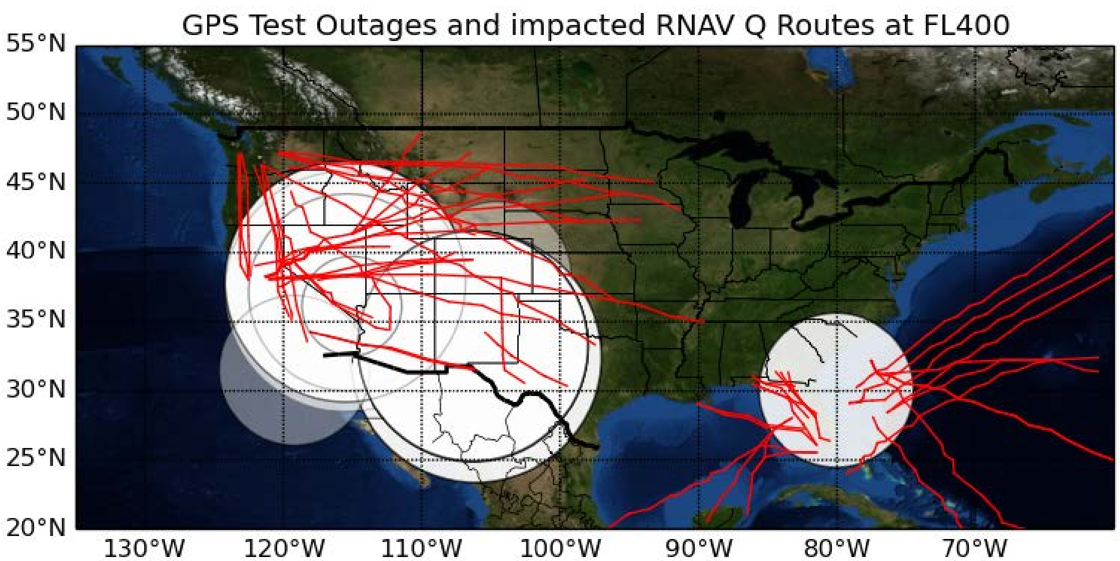


Figure 9-2 GPS Test NOTAMs @ FL250

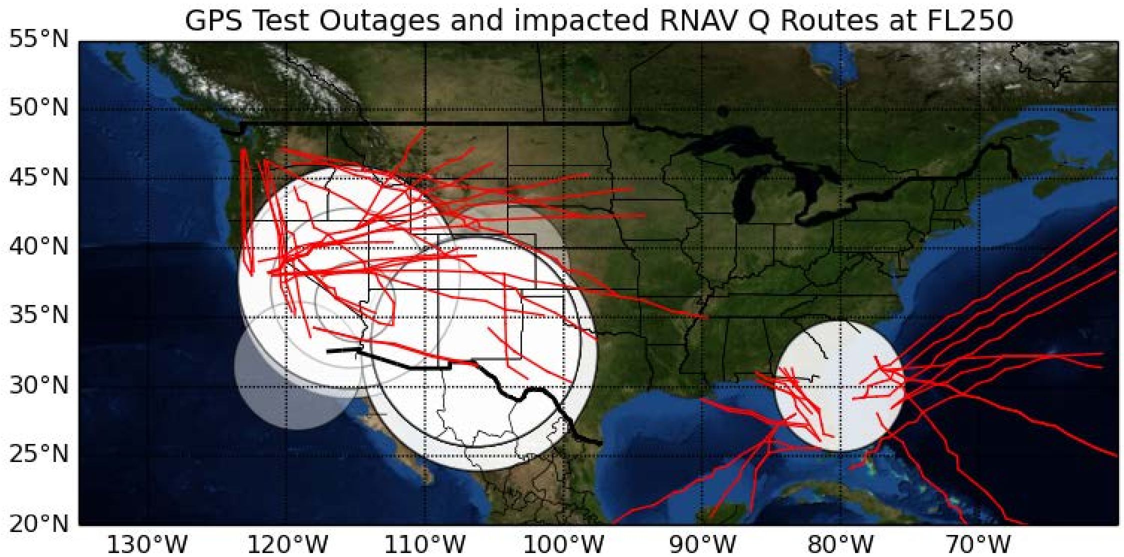


Figure 9-3 GPS Test NOTAMs @ 10,000 Feet

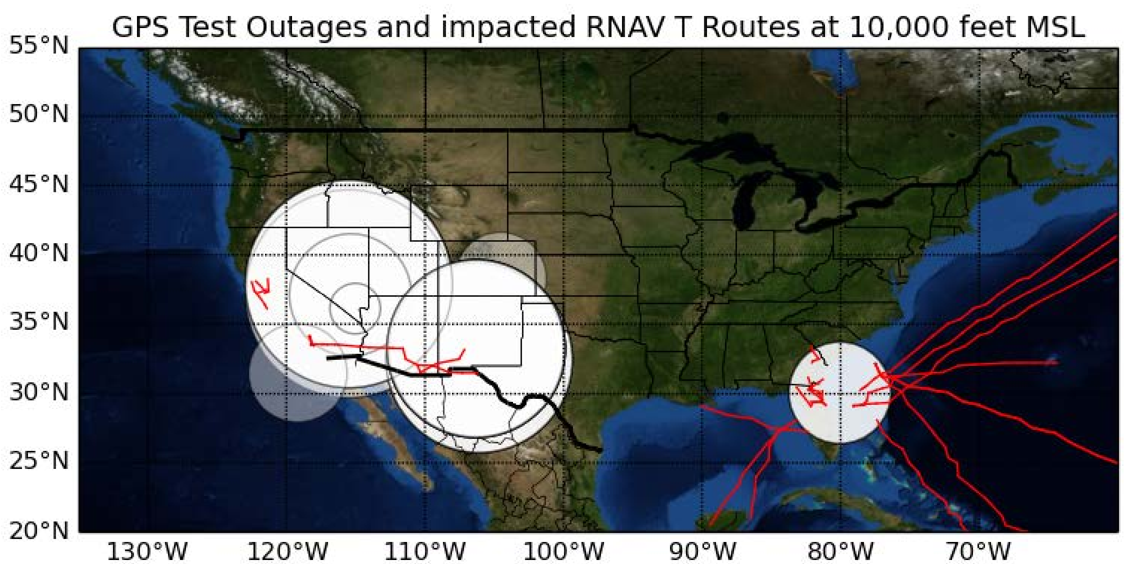


Figure 9-4 GPS Test NOTAMs @ 4,000 Feet

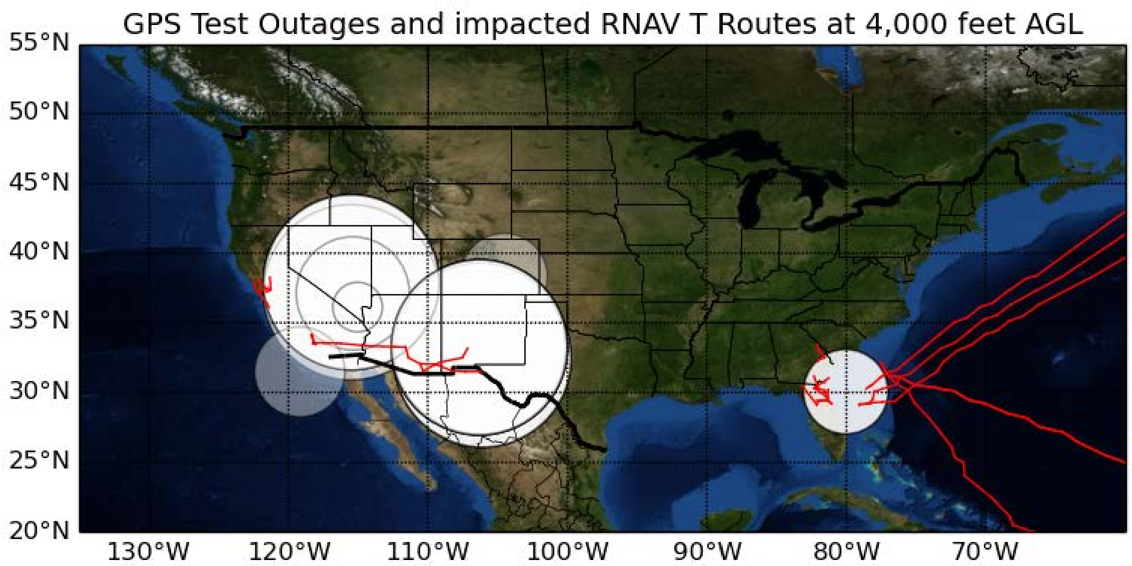
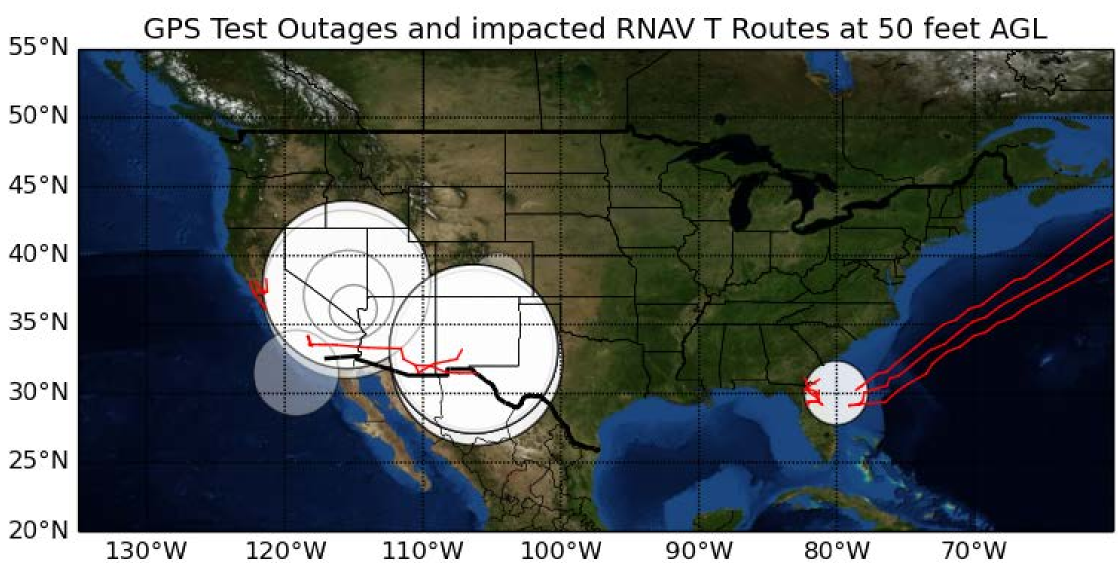


Figure 9-5 GPS Test NOTAMs @ 50 Feet



9.3 GPS Availability

The impacts to GPS availability are listed below for the corresponding locations and times. The percent impact to GPS availability over CONUS indicates that GPS is impacted for *X* % of the total area (total area of CONUS), centered at the indicated latitude/longitude. The last five columns in the table represent the impact to GPS availability at the corresponding altitude range. Altitudes 4,000 feet and under are with respect to above ground level (AGL), all remaining altitudes are with respect to MSL (mean sea level). Each row of the following table represents one published GPS Test NOTAM.

Table 9-3 NOTAM Impact to GPS Availability

Start Date	End Date	Latitude	Longitude	Percent Impact at each altitude				
				50	4000	10000	FL250	FL400
2015-01-08 18:30:00	2015-01-09 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-01-12 18:30:00	2015-01-15 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-01-14 14:00:00	2015-01-14 18:00:00	30.0500N	-80.0500W	1.24	1.86	3.10	4.85	6.71
2015-01-14 20:00:00	2015-01-14 23:00:00	30.0500N	-80.0500W	1.24	1.86	3.10	4.85	6.71
2015-01-17 15:00:00	2015-01-17 23:00:00	30.0500N	-80.0500W	1.24	1.86	3.10	4.85	6.71
2015-01-17 18:30:00	2015-01-17 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-01-18 13:00:00	2015-01-19 21:00:00	30.0500N	-80.0500W	1.24	1.86	3.10	4.85	6.71
2015-01-25 05:00:00	2015-01-25 09:30:00	37.9000N	-115.5023W	14.55	15.79	20.02	22.08	24.97
2015-01-26 08:00:00	2015-01-26 12:00:00	37.9000N	-115.5023W	14.55	15.79	20.02	22.08	24.97
2015-01-28 05:30:00	2015-01-28 08:00:00	37.9000N	-115.5023W	14.55	15.79	20.02	22.08	24.97
2015-01-29 05:30:00	2015-01-29 08:45:00	37.9000N	-115.5023W	14.55	15.79	20.02	22.08	24.97
2015-01-29 17:00:00	2015-01-29 18:30:00	36.1307N	-115.0308W	1.14	1.14	1.24	3.30	5.26
2015-01-29 18:30:00	2015-01-29 20:00:00	37.9000N	-115.5023W	14.55	15.79	20.02	22.08	24.97
2015-01-30 05:30:00	2015-01-31 08:00:00	37.9000N	-115.5023W	14.55	15.79	20.02	22.08	24.97
2015-02-04 04:00:00	2015-02-07 13:30:00	37.1900N	-115.5023W	13.93	14.65	18.68	20.95	23.22
2015-02-06 18:30:00	2015-02-06 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-02-09 18:30:00	2015-02-09 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-02-11 04:00:00	2015-02-13 13:30:00	37.1900N	-115.5023W	13.93	14.65	18.68	20.95	23.22
2015-02-11 18:30:00	2015-02-12 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-02-18 04:00:00	2015-02-18 12:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-02-20 04:00:00	2015-02-20 12:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-02-21 05:30:00	2015-02-28 12:00:00	38.3114N	-104.5515W	1.44	4.13	4.44	10.53	11.97
2015-02-23 18:30:00	2015-02-24 22:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-02-26 18:30:00	2015-02-28 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2015-03-04 03:00:00	2015-03-05 10:00:00	37.1116N	-115.3752W	4.44	6.60	8.05	12.59	17.65
2015-03-06 04:00:00	2015-03-07 10:00:00	37.1116N	-115.3752W	4.44	6.60	8.05	12.59	17.65
2015-03-10 05:00:00	2015-03-13 07:00:00	37.1116N	-115.3752W	4.44	6.60	8.05	12.59	17.65
2015-03-11 18:30:00	2015-03-11 22:30:00	33.1650N	-106.2915W	10.73	11.97	12.69	17.13	20.64
2015-03-13 06:00:00	2015-03-14 11:00:00	33.1650N	-106.2915W	10.73	11.97	12.69	17.13	20.64
2015-03-13 18:30:00	2015-03-14 22:30:00	33.1650N	-106.2915W	10.73	11.97	12.69	17.13	20.64
2015-03-17 03:00:00	2015-03-18 12:00:00	33.1650N	-106.2915W	10.73	11.97	12.69	17.13	20.64
2015-03-17 07:00:00	2015-03-20 12:30:00	31.4800N	-119.1800W	0.83	0.93	1.03	2.27	2.99
2015-03-19 04:30:00	2015-03-21 13:30:00	33.1650N	-106.2915W	10.73	11.97	12.69	17.13	20.64
2015-03-27 18:30:00	2015-03-27 22:30:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2015-03-28 04:30:00	2015-03-28 13:30:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2015-03-28 18:30:00	2015-03-28 22:30:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2015-03-29 03:00:00	2015-03-30 07:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2015-03-29 18:30:00	2015-03-30 22:30:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39

10 Appendices

10.1 Appendix A: Performance Summary

Table 10-1 Performance Summary

User Range Error Accuracy	**Conditions and Constraints**	**Measured Performance**
Single Frequency C/A-Code • ≤ 7.8m 95% Global Average URE during normal operations over All AODs • ≤ 6.0m 95% Global Average URE during operations at Zero AOD • ≤ 12.8m 95% Global Average URE during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1	≤ 3.856 m N/A N/A
Single Frequency C/A-Code • ≤ 30m 99.94% Global Average URE during normal operations • ≤ 30m 99.79% Worst Case single point average during normal operations.	• For any healthy SPS SIS. • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 • Standard based on measurement interval of one year; average of daily values within service volume • Standard based on 3 service failures per year, lasting no more than 6 hours each	100% Global 100% WCP
User Range Rate Error Accuracy	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	≤ 3.359 mm/sec
User Range Acceleration Error Accuracy	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 2 mm/sec^2 95% Global average URAE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	≤ 0.025 mm/s^2

Per-Satellite Coverage	Conditions and Constraints	Measured Performance
Terrestrial Service Volume: • 100% Coverage	• For any health or marginal SPS SIS	100%
Constellation Coverage	**Conditions and Constraints**	
Terrestrial Service Volume: • 100% Coverage	• For any health or marginal SPS SIS	100%
Status and Problem Reporting	**Conditions and Constraints**	
Scheduled event affecting service • Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS	≥ 74.917 hours Prior to event
Unscheduled outage or problem affecting service • Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	• For any SPS SIS	1.683 hours
Unscheduled Failure Interruption Continuity • ≥ 0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption.	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Given that the SPS SIS is available from the slot at the start of the hour.	100%
Operational Satellite Count	**Conditions and Constraints**	
• ≥ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not	• Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operation satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.	100%
PDOP Availability	**Conditions and Constraints**	
• ≥ 98% global PDOP of 6 or less • ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval	100 % 100 %
Service Availability	**Conditions and Constraints**	
• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical

Position/Time Accuracy	Conditions and Constraints	
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 3.097 m Horizontal ≤ 5.044 m Vertical
Worst Site Position Domain Accuracy • ≤ 17m 95% Horizontal Error • ≤ 37m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 9.023 m Horiz. ≤ 8.362 m Vert.
Time Transfer Domain Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for a time transfer solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 14 nanoseconds
Instantaneous UTCOE Integrity • NTE ±120 nanoseconds 99.999% of time without a timely alert (SIS only)	• For any healthy SPS SIS • Worst case for delayed alert is 6 hours	≤ 47.2 nanoseconds
Per-Slot Availability	**Conditions and Constraints**	
• ≥ 0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS • ≥ 0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SPS SIS	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.	100% 100%
Constellation Availability	**Conditions and Constraints**	
• ≥ 0.98 Probability that at least 21 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration • ≥ 0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration	• Calculated as an average over all slots in the 24-slot constellation, normalized annually. • Applies to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.	100% 100%

10.2 Appendix B: Geomagnetic Data

Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center

Current Quarter Daily Geomagnetic Data

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2015 01 01	7	2 2 1 1 2 2 2 3	5	1 1 2 1 2 2 1 2	7	2 1 1 1 1 2 2 3
2015 01 02	8	3 1 1 2 2 2 2 3	17	2 2 3 2 5 2 4 3	12	3 1 2 2 3 2 3 4
2015 01 03	13	4 2 3 3 3 3 2 1	18	4 3 3 5 4 2 1 0	15	5 3 3 3 3 2 2 1
2015 01 04	15	0 0 3 4 4 3 2 4	48	0 0 4 7 6 6 4 4	21	1 1 2 4 4 5 4 5
2015 01 05	10	4 2 2 2 2 2 2 2	18	4 3 4 3 3 3 3 3	18	5 3 3 2 2 2 3 3
2015 01 06	11	2 2 3 3 2 3 3 1	20	2 2 4 5 4 4 3 0	13	2 3 3 4 2 3 3 2
2015 01 07	23	2 2 5 5 4 3 2 4	59	2 0 7 8 5 3 3 2	38	3 1 6 7 4 2 3 4
2015 01 08	15	3 5 3 2 2 3 1 2	23	3 3 3 4 5 5 2 2	16	4 4 3 2 2 3 2 3
2015 01 09	7	2 1 3 2 2 2 1 1	8	2 1 2 2 4 2 1 0	8	3 2 3 2 2 2 2 2
2015 01 10	9	1 3 2 2 3 3 2 1	18	1 2 2 5 5 4 1 0	10	2 3 2 2 3 3 1 0
2015 01 11	8	3 1 3 2 2 1 2 1	18	1 1 5 5 4 2 2 1	10	3 2 3 2 2 1 2 2
2015 01 12	7	1 1 1 2 3 2 2 2	16	0 1 1 3 6 3 2 2	8	0 1 1 2 3 2 3 2
2015 01 13	5	1 1 1 1 2 2 2 2	13	1 1 1 3 5 3 2 2	8	2 2 1 2 3 2 2 2
2015 01 14	5	2 1 1 2 2 2 1 1	12	1 1 1 4 5 2 1 0	7	2 1 2 2 3 1 2 1
2015 01 15	5	1 1 1 1 3 2 1 1	14	0 0 4 3 5 3 1 1	6	1 1 2 1 3 2 1 1
2015 01 16	6	1 2 2 1 2 2 2 1	10	0 1 3 4 4 1 1 1	7	1 3 2 2 2 1 2 2
2015 01 17	5	3 2 0 2 1 0 1 1	2	0 1 0 3 0 0 0 0	7	3 3 1 2 1 0 1 2
2015 01 18	3	0 2 0 0 2 1 2 1	2	0 0 0 1 1 1 0 1	5	0 1 0 1 2 1 2 2
2015 01 19	2	2 0 0 0 1 1 1 1	2	0 0 0 1 1 2 1 1	5	3 1 1 1 1 1 1 2
2015 01 20	5	1 1 2 2 1 1 1 2	4	1 0 1 4 0 0 0 0	4	1 1 2 1 1 0 1 1
2015 01 21	7	2 2 1 1 1 2 3 2	10	0 0 0 1 4 4 3 2	11	2 2 2 1 2 3 4 3
2015 01 22	9	3 3 2 2 2 2 2 2	19	3 3 1 5 5 3 2 1	12	4 3 2 3 3 2 2 2
2015 01 23	8	2 3 2 2 2 2 2 1	8	2 2 2 2 3 3 1 1	9	3 3 3 2 2 2 2 1
2015 01 24	5	0 1 1 2 2 2 1 2	7	0 0 0 3 4 2 1 1	7	1 2 1 2 2 2 2 2
2015 01 25	3	0 1 0 0 1 1 1 3	4	0 0 0 3 2 2 1 1	6	1 2 1 0 1 1 1 3
2015 01 26	12	3 2 3 4 3 2 2 1	19	2 1 4 5 4 4 2 1	16	3 3 3 4 3 3 2 2
2015 01 27	9	3 2 3 2 2 2 2 2	13	2 2 3 4 3 3 2 2	12	3 3 3 2 2 3 3 3
2015 01 28	5	2 1 3 2 1 1 0 1	14	2 2 3 5 4 1 1 1	7	3 2 3 2 1 1 1 1
2015 01 29	7	2 1 1 1 2 2 3 2	8	1 0 1 3 2 3 3 2	9	2 1 1 2 2 2 4 3
2015 01 30	8	2 3 2 1 1 2 3 2	9	1 2 3 3 2 2 2 2	11	3 3 2 1 1 2 3 3
2015 01 31	6	1 2 1 1 1 2 2 3	8	1 2 0 3 2 3 2 2	9	2 2 1 2 2 2 2 4
2015 02 01	11	3 1 2 2 2 3 3 3	17	3 1 2 3 3 4 4 4	21	4 3 3 2 2 3 4 5
2015 02 02	17	4 4 3 3 3 3 3 2	44	4 5 5 6 4 6 4 3	27	5 5 4 4 3 4 4 3
2015 02 03	12	3 4 2 2 2 2 2 3	28	3 3 5 5 4 5 3 2	17	4 4 3 2 2 3 3 3
2015 02 04	5	2 1 1 2 2 2 1 1	14	1 2 2 3 5 3 2 2	9	3 2 2 2 3 3 1 2
2015 02 05	10	1 3 1 3 3 3 2 2	21	0 2 1 3 5 6 2 2	13	2 3 1 3 3 4 3 2
2015 02 06	4	0 1 2 2 2 2 1 0	4	1 1 1 2 2 1 1 0	5	1 1 2 2 2 1 1 0
2015 02 07	9	1 0 3 4 2 2 1 2	23	0 0 3 6 5 4 2 1	9	1 0 3 3 2 3 2 2
2015 02 08	7	1 2 2 2 2 2 2 2	14	1 2 5 4 2 2 2 2	10	2 3 3 2 2 2 3 3
2015 02 09	5	2 0 1 0 2 2 2 2	7	2 0 0 1 4 3 1 1	8	3 1 1 1 3 2 2 3
2015 02 10	6	1 2 1 1 2 2 2 2	3	0 1 0 0 2 1 1 2	7	1 3 1 1 1 2 2 3
2015 02 11	5	2 3 0 0 2 2 1 1	8	1 1 0 2 5 1 0 0	7	2 3 1 1 2 1 0 1
2015 02 12	3	1 0 0 1 2 1 1 1	4	0 0 0 0 3 3 1 0	5	2 1 1 1 2 2 2 1
2015 02 13	2	0 0 0 1 2 1 1 1	2	0 0 0 3 1 0 0 0	3	0 0 0 1 1 1 1 1
2015 02 14	2	0 1 1 0 1 1 1 1	0	0 0 0 0 0 0 0 1	3	0 1 1 1 0 0 1 1
2015 02 15	5	0 2 2 1 3 1 1 1	11	1 0 2 3 5 3 1 0	6	1 2 2 2 3 1 1 1
2015 02 16	4	0 1 0 1 2 1 2 2	3	0 0 2 2 1 0 1 1	5	0 1 1 1 1 1 2 3
2015 02 17	18	3 2 3 3 3 3 3 5	27	2 2 3 6 3 5 3 4	22	3 3 3 4 3 3 4 5
2015 02 18	15	5 3 3 3 2 2 2 2	28	4 4 5 5 5 3 2 1	19	5 4 3 3 2 2 2 3
2015 02 19	5	2 2 2 1 1 2 1 1	8	1 2 3 1 3 3 1 1	8	3 3 2 1 1 2 2 2
2015 02 20	4	0 2 2 1 2 1 1 1	7	1 0 2 3 4 1 0 1	6	1 2 2 2 2 1 1 2

2015 02 21	8	3 3 1 1 2 2 2 2	6	2 2 2 3 1 1 0 1	7	3 3 1 1 2 1 1 2
2015 02 22	6	2 1 1 2 2 2 1 2	7	1 2 1 3 3 2 1 0	7	3 2 1 2 1 1 1 2
2015 02 23	14	3 2 2 3 3 4 2 3	25	2 1 4 5 5 5 3 2	17	3 3 3 3 3 4 3 4
2015 02 24	21	5 4 4 4 2 3 2 2	41	5 5 6 6 5 3 2 1	25	5 5 4 4 3 2 2 3
2015 02 25	7	2 1 3 2 3 2 1 0	20	0 0 3 6 5 2 2 0	9	1 1 3 2 3 2 1 1
2015 02 26	5	2 1 2 1 1 2 1 1	8	1 0 4 3 3 1 0 0	5	2 1 2 2 1 0 1 1
2015 02 27	2	0 0 0 0 1 2 1 1	1	0 0 0 0 1 1 0 1	4	1 0 1 1 1 1 1 2
2015 02 28	11	1 2 3 1 2 4 2 3	18	1 1 3 4 3 5 3 3	13	1 3 3 2 2 4 3 3
2015 03 01	23	5 4 5 4 3 2 2 2	36	4 5 5 7 2 1 2 2	28	5 5 5 4 2 2 2 3
2015 03 02	18	4 3 4 4 3 3 3 1	60	3 5 8 6 5 4 3 1	28	4 4 5 5 4 4 3 2
2015 03 03	10	3 3 2 2 2 2 1 3	21	1 2 3 6 5 1 1 2	11	3 3 2 2 2 1 2 3
2015 03 04	9	1 1 1 3 3 2 2 3	12	1 1 1 5 4 1 1 1	10	2 2 2 3 3 1 2 3
2015 03 05	5	0 0 0 1 3 2 2 2	7	0 0 0 3 4 2 2 1	6	1 1 1 2 2 2 2 2
2015 03 06	9	1 2 4 2 2 2 2 2	17	1 3 5 4 4 2 2 1	13	2 3 4 3 2 2 3 3
2015 03 07	17	4 4 3 3 1-1-1 3	27	3 4 5 5 2-1-1 3	20	4 4 3 3 2 4 3 4
2015 03 08	7	2 2 2 2 3 2 1 1	24	3 1 5 5 5 4 1 1	11	3 2 3 3 4 2 2 1
2015 03 09	6	4 1 0 0 2 2 1 1	2	1 1 0 0 0 1 1 0	6	3 2 1 0 1 1 1 1
2015 03 10	4	1 1 2 2 1 2 1 0	6	1 1 1 4 1 1 1 0	5	2 2 2 2 1 1 1 1
2015 03 11	8	0 3 2 2 2 3 2 1	14	1 2 3 3 4 4 3 1	9	1 3 2 2 2 3 2 1
2015 03 12	6	1 3 2 2 2 2 1 0	13	1 2 3 5 3 2 2 0	8	2 3 2 3 2 2 1 0
2015 03 13	5	1 0 0 1 3 3 1 1	-1	1-1-1-1-1-1-1-1	6	1 1 1 1 3 2 1 1
2015 03 14	5	0 2 1 2 2 2 1 2	-1	1-1-1-1-1-1-1-1	5	1 2 2 2 2 1 1 2
2015 03 15	7	1 2 3 1 2 2 2 2	-1	-1-1-1-1-1-1-1-1	7	2 2 3 2 1 2 2 1
2015 03 16	9	2 3 3 2 2 2 2 2	0	-1-1-1-1-1-1 0 0	11	2 3 3 3 2 3 1 1
2015 03 17	46	2 4 5 4 6 5 5 6	106	2 3 6 6 8 8 7 5	117	2 5 6 6 8 8 7 8
2015 03 18	32	5 4 3 4 5 5 3 4	60	4 4 6 6 6 7 4 3	52	6 5 4 5 5 6 5 5
2015 03 19	19	4 4 3 4 4 2 2 3	47	3 4 5 6 7 4 4 3	28	4 4 4 5 5 3 3 4
2015 03 20	18	4 2 4 3 3 3 2 4	32	4 3 5 6 4 3 4 3	24	5 3 5 3 3 3 3 5
2015 03 21	12	4 2 3 3 2 2 2 2	18	3 2 5 4 4 2 2 1	14	4 3 4 3 2 2 2 2
2015 03 22	16	2 3 5 4 3 2 1 1	39	2 3 7 5 6 3 1 1	24	2 3 6 4 4 1 1 1
2015 03 23	16	4 4 2 3 3 3 2 3	31	3 4 3 5 5 6 2 2	21	4 5 3 3 4 3 2 3
2015 03 24	9	2 1 2 2 3 3 2 2	15	2 1 0 4 4 5 2 1	12	2 2 2 2 3 4 2 2
2015 03 25	10	2 2 2 3 3 2 3 2	20	2 2 3 6 3 3 3 1	13	2 2 3 4 3 2 3 2
2015 03 26	7	1 1 2 1 2 2 2 3	5	2 1 2 0 2 2 1 2	8	2 1 2 1 2 2 2 3
2015 03 27	7	2 2 1 2 3 2 1 2	14	2 3 2 3 4 4 2 1	9	3 3 2 2 3 1 1 2
2015 03 28	9	0 1 3 2 2 3 2 3	6	0 2 3 3 1 1 1 1	9	0 2 3 3 2 2 2 3
2015 03 29	11	3 3 3 2 3 1 2 2	14	4 3 3 3 4 2 1 1	14	4 3 3 3 3 1 2 2
2015 03 30	5	2 2 0 1 3 1 1 1	3	2 2 1 2 0 0 0 0	5	2 2 1 1 1 1 1 2
2015 03 31	7	1 1 2 2 3 2 2 2	7	0 1 2 3 3 2 2 1	9	1 1 2 2 3 2 3 2

10.3 Appendix C: Performance Analysis (PAN) Problem Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS for IFR and is developing WAAS and LAAS, both of which are GPS augmentation systems. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Performance Analysis (PAN) report. The PAN report contains data collected at various National Satellite Test Bed (NSTB) and Wide Area Augmentation System (WAAS) reference station locations. This PAN Problem Report will be issued only when the performance data fails to meet the GPS Standard Positioning Service (SPS) Signal Specification.

Problem Description:

There were no problems this quarter.

10.4 Appendix D: Glossary

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (September 2008). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

General Terms and Definitions

Almanac Longitude of the Ascending Node (.o): Equatorial angle from the Prime Meridian (Greenwich) at the weekly epoch to the ascending node at the ephemeris reference epoch.

Coarse/Acquisition (C/A) Code: A PRN code sequence used to modulate the GPS L1 carrier.

Corrected Longitude of Ascending Node (Ωk) and Geographic Longitude of the Ascending Node (GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the ascending node, both at arbitrary time T_k.

Dilution of Precision (DOP): The magnifying effect on GPS position error induced by mapping GPS ranging errors into position within the specified coordinate system through the geometry of the position solution. The DOP varies as a function of satellite positions relative to user position. The DOP may be represented in any user local coordinate desired. Examples are HDOP for local horizontal, VDOP for local vertical, PDOP for all three coordinates, and TDOP for time.

Equatorial Angle: An angle along the equator in the direction of Earth rotation.

Geometric Range: The difference between the estimated locations of a GPS satellite and an SPS receiver.

Ground track Equatorial Crossing (GEC, λ, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ωk when the argument of latitude (Φ) is zero.

Instantaneous User Range Error (URE): The difference between the pseudo range measured at a given location and the expected pseudo range, as derived from the navigation message and the true user position, neglecting the bias in receiver clock relative to GPS time. A signal-in-space (SIS) URE includes residual orbit, satellite clock, and group delay errors. A system URE (sometimes known as a User Equivalent Range Error, or UERE) contains all line-of-sight error sources, to include SIS, single-frequency ionosphere model error, troposphere model error, multipath and receiver noise.

Longitude of Ascending Node (LAN): A general term for the location of the ascending node – the point that an orbit intersects the equator when crossing from the Southern to the Northern hemisphere.

Longitude of the Ground track Equatorial Crossing (GEC, λ, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ωk when the argument of latitude (Φ) is zero.

Mean Down Time (MDT): A measure of time required to restore function after any downing event.

Mean Time Between Downing Events (MTBDE): A measure of time between any downing events.

Mean Time Between Failures (MTBF): A measure of time between unscheduled downing events.

Mean Time to Restore (MTTR): A measure of time required to restore function after an unscheduled downing event.

Navigation Message: Data contained in each satellite's ranging signal and consisting of the ranging signal time-of-transmission, the transmitting satellite's orbital elements, an almanac containing abbreviated orbital element information to support satellite selection, ranging measurement correction information, and status flags. The message structure is described in Section 2.1.2 of the SPS Performance Standard.

Operational Satellite: A GPS satellite which is capable of, but is not necessarily transmitting a usable ranging signal.

PDOP Availability: Defined to be the percentage of time over any 24-hour interval that the PDOP value is less than or equal to its threshold for any point within the service volume.

Positioning Accuracy: Defined to be the statistical difference, at a 95% probability, between position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

- **Horizontal Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between horizontal position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

- **Vertical Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

Position Solution: An estimate of a user's location derived from ranging signal measurements and navigation data from GPS.

Position Solution Geometry: The set of direction cosines that define the instantaneous relationship of each satellite's ranging signal vector to each of the position solution coordinate axes.

Pseudo Random Noise (PRN): A binary sequence that appears to be random over a specified time interval unless the shift register configuration and initial conditions for generating the sequence are known. Each satellite generates a unique PRN sequence that is effectively uncorrelated (orthogonal) to any other satellite's code over the integration time constant of a receiver's code tracking loop.

Representative SPS Receiver: The minimum signal reception and processing assumptions employed by the U.S. Government to characterize SPS performance in accordance with performance standards defined in Section 3 of the SPS Performance Standard. Representative SPS receiver capability assumptions are identified in Section 2.2 of the SPS Performance Standard.

Right Ascension of Ascending Node (RAAN): Equatorial angle from the celestial principal direction to the ascending node.

Root Mean Square (RMS) SIS URE: A statistic that represents instantaneous SIS URE performance in an RMS sense over some sample interval. The statistic can be for an individual satellite or for the entire constellation. The sample interval for URE assessment used in the SPS Performance Standard is 24 hours.

Selective Availability: Protection technique formerly employed to deny full system accuracy to unauthorized users. SA was discontinued effective midnight May 1, 2000.

Service Availability: Defined to be the percentage of time over any 24-hour interval that the predicted 95% positioning error is less than its threshold for any given point within the service volume.

- **Horizontal Service Availability:** Defined to be the percentage of time over any 24-hour interval that the predicted 95% horizontal error is less than its threshold for any point within the service volume.

- **Vertical Service Availability:** Defined to be the percentage of time over any 24-hour interval that the predicted 95% vertical error is less than its threshold for any point within the service volume.

Service Degradation: A condition over a time interval during which one or more SPS performance standards are not supported.

Service Failure: A condition over a time interval during which a healthy GPS satellite's ranging signal exceeds the Not-to-Exceed (NTE) SPS SIS URE tolerance.

Service Reliability: The percentage of time over a specified time interval that the instantaneous SIS SPS URE is maintained within a specified reliability threshold at any given point within the service volume, for all healthy GPS satellites.

Service Volume: The spatial volume supported by SPS performance standards. Specifically, the SPS Performance Standard supports the terrestrial service volume. The terrestrial service volume covers from the surface of the Earth up to an altitude of 3,000 kilometers.

SPS Performance Envelope: The range of nominal variation in specified aspects of SPS performance.

SPS Performance Standard: A quantifiable minimum level for a specified aspect of GPS SPS performance. SPS performance standards are defined in Section 3.0.

SPS Ranging Signal: An electromagnetic signal originating from an operational satellite. The SPS ranging signal consists of a Pseudo Random Noise (PRN) C/A code, a timing reference and sufficient data to support the position solution generation process. A description of the GPS SPS signal is provided in Section 2. The formal definition of the SPS ranging signal is provided in ICD IS-GPS-200G.

SPS Ranging Signal Measurement: The difference between the ranging signal time of reception (as determined by the receiver's clock) and the time of transmission derived from the navigation signal (as defined by the satellite's clock) multiplied by the speed of light. Also known as the *pseudo range*.

SPS SIS User Range Error (URE) Statistic:

- A satellite SPS SIS URE statistic is defined to be the Root Mean Square (RMS) difference between SPS ranging signal measurements (neglecting user clock bias and errors due to propagation environment and receiver), and "true" ranges between the satellite and an SPS user at any point within the service volume over a specified time interval.

- A constellation SPS SIS URE statistic is defined to be the average of all satellite SPS SIS URE statistics over a specified time interval.

Time Transfer Accuracy Relative to UTC (USNO): The difference at a 95% probability between user UTC time estimates and UTC (USNO) at any point within the service volume over any 24-hour interval.

Transient Behavior: Short-term behavior not consistent with steady-state expectations.

Usable SPS Ranging Signal: An SPS ranging signal that can be received, processed, and used in a position solution by a receiver with representative SPS receiver capabilities.

User Navigation Error (UNE): Given a sufficiently stationary and ergodic satellite constellation ranging error behavior over a minimum sample interval, multiplication of the DOP and a constellation ranging error standard deviation value will yield an approximation of the RMS position error. This RMS approximation is known as the UNE (UHNE for horizontal, UVNE for vertical, and so on). The user is cautioned that any divergence away from the stationary and ergodic assumptions will cause the UNE to diverge from a RMS value based on actual measurements.

User Range Accuracy (URA): A conservative representation of each satellite's expected (1σ) SIS URE performance (excluding residual group delay) based on historical data. A URA value is provided that is representative over the curve fit interval of the navigation data from which the URA is read. The URA is a coarse representation of the URE statistic in that it is quantized to levels represented in ICD IS-GPS-200G.